Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling

CONSULTANT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the Alternatives to Compressor Cooling Project, Contract No. 500-98-024, conducted by the Davis Energy Group (DEG). The report is entitled "Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling." This project contributes to the PIER Buildings End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Energy Commission's Web site at http://www.energy.ca.gov/research/index.html or contact the Energy Commission's Publications Unit at 916-654-5200.

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Background

Residential buildings are responsible for 37% of California's peak load, and air conditioning accounts for 45% of residential peak load but only 7% of residential energy use (Coito 2003). Results from four prior phases of the Alternatives to Compressor Cooling (ACC) project found that mechanically ventilating homes with cool night air could mitigate this peak load problem by eliminating the need for air conditioning in California "transition" climates that are influenced by coastal temperatures. In the fourth ACC project phase, preliminary work was completed to develop the hardware and controls needed to provide ventilation cooling, and home designs were completed for transition climates. This report describes a fifth phase of work by the Davis Energy Group under this project to complete development of ventilation cooling systems, to extend ACC designs to hot inland climates, to demonstrate them in two climates, and to evaluate performance in all sixteen California climate zones.

Objectives & Approach

Integrated HVAC System Development

A primary objective of this project phase (Phase 5) was to complete development of an integrated heating, ventilation cooling, and air conditioning system that would also provide fresh air ventilation for maintaining indoor air quality. This required development of both controls and an air handler with outside air damper. To assure marketability the system would have to be easily installed by contractors, reliable, and affordable. Other design goals included improved comfort and indoor air quality, and lower energy use relative to conventional systems.

Expanding on prior work, interviews and surveys were used to identify optimal strategies for conveying the concepts of, and controlling, ventilation cooling. This information was used to develop a functional specification for controls that guided control hardware development and programming. Prototype controls were evaluated using web simulations and actual installations, and improvements were implemented.

A hot water (hydronic) air handler was chosen as the air-moving device for ventilation cooling to avoid gas furnace control complications and approval issues, and to take advantage of opportunities for reducing winter fan energy use. A variable speed air handler was designed and a prototype was assembled. Following a review of damper alternatives, an available residential economizer damper was selected to provide a source of outside air to the air handler. Testing was completed to identify performance characteristics and to evaluate durability. A relationship was established with an HVAC equipment manufacturer, who built three air handlers to be used for demonstration purposes. The name "NightBreeze" was selected to represent the air handler, damper, and control system.

Extension to Inland Climates
To compliment transition climate home designs prepared in previous project phases, an "Inland Valley" ACC house design was developed that includes several measures to improve summer performance in hotter climates in addition to ventilation cooling. Performance of this house was simulated using a special version of the DOE-2 computer program that was modified to include the same control functions as were developed for the NightBreeze system. Simulations were used to predict peak demand reduction and energy savings in six representative California climate zones.

Understanding the market and technical potential for ventilation cooling requires knowledge of how people use their thermostats, their conceptions of comfort, and how they use windows for ventilation. Fifty homeowners were interviewed to obtain answers to these questions. In addition, a thorough literature review on the subject of residential comfort was completed and a "comfort report" was prepared. This report summarizes current thinking and contributes new material, and proposes criteria for defining residential comfort.

Demonstrations
Two production builders, Centex Homes and Clarum Homes, were selected to demonstrate ACC concepts and systems. The home built by Centex is a 3080 ft^2 one-story home located in Livermore (Climate Zone 12, a hot inland climate zone). The two-story 1611 ft^2 home built by Clarum is located in Watsonville (Climate Zone 3, a transition climate zone). Measures installed in both homes included high performance windows (a standard feature in both developments), radiant barrier roof sheathing, 5/8" thick drywall instead of the standard ½" material and greater than 50% hard surface flooring for improved thermal mass, and NightBreeze HVAC systems. High efficiency water heaters were installed to serve as a heat source for both domestic hot water and space heating. To accommodate the hotter climate, trellises for window shading and slab perimeter insulation were also installed at the Livermore site. The construction process was observed to identify any potential implementation barriers, and incremental construction costs for the ACC measures were obtained.

The two demonstration homes were monitored for more than one year each. Monitoring data were used to calibrate the DOE-2 model (with special control function), and the model was used to estimate demand reduction and energy savings in all sixteen California climate zones.

Project Outcomes

Integrated HVAC System Development
An integrated heating, ventilation cooling, air conditioning and fresh air ventilation system ("NightBreeze") was built, tested, and successfully demonstrated. The system includes a hot water air handler, damper, and controls. The air handler utilizes an electronically commutated motor (ECM) that provides variable speed operation for heating, ventilation cooling, and fresh air ventilation. This DC motor is highly efficient at low as well as high speeds. The outside air damper selects between outside air and return air, filters both, and provides air relief to outside so that windows do not have to be opened. Testing by Pacific Gas and Electric Company verified air handler

performance and found acceptable damper reliability and leakage rates. System features include:

- A “user friendly” wall display unit (thermostat) that integrates control of heating, ventilation cooling, air conditioning, and fresh air ventilation and provides feedback on the consequences of user settings.
- Control functions that predict future temperature conditions in order to provide information to the user about optimal comfort settings, to adjust ventilation cooling rates to minimize fan energy use and avoid overcooling, and to minimize air conditioner operation.
- Quiet, variable speed heating, and heating fan energy use that is less than half that of typical furnaces.
- Winter fresh air ventilation that precisely meets ASHRAE Standard 62 air change requirements while using less fan energy than any other mechanical fresh air system available.

A limited quantity of NightBreeze systems is being built for additional demonstrations and custom home projects. A production readiness plan has been written for use in manufacturing units and this technology is ready for full commercialization.

Extension to Inland Climates
Major project accomplishments toward extending ACC technology to inland climates and transitional climates include:

- Architectural and mechanical designs for an Inland Climate house that reduces energy demand by a predicted 49% and energy use by 75% in Climate Zone 12 compared to a similar house built to the current California Energy Commission’s Title 24 building standards.
- Application of summer performance measures that have no impact on house appearance.
- Development of a special function for the DOE-2 program that allows simulation of NightBreeze systems with any home design and in any climate.
- Development of survey data on homeowner behavior and comfort expectations that can contribute to marketing efforts and that can be used in other studies of residential energy use.
- A report that describes new criteria for defining comfort in residential buildings and serves as reference for future comfort studies (Attachment 6).

Demonstrations
ACC design principles were successfully demonstrated at the Watsonville and Livermore sites, and the houses were both monitored for more than one year. The Watsonville house maintained comfortable temperatures without air conditioning installed. The Livermore house operated its two air conditioners a combined total of 8.9 hours (average of 3½ minutes per day) during the summer of 2003, which included 15

days with temperatures over 100°F. Other outcomes determined from monitoring data are as follows:

- Total annual HVAC electric use was 93 kWh for the Watsonville house and 901 kWh for the Livermore house, of which 85% was used during off-peak hours.
- Average monthly maximum peak summer demand by HVAC systems was 2.2 kW for the Livermore house (2003) and 0.04 kW for the Watsonville house (2002).
- Two tons of air conditioning would have maintained comfort at the Livermore house instead of the four tons, which were installed.
- On a typical summer day (July 25, 2003) the Livermore demonstration house used about one fifth of the cooling (fan and compressor) energy as a "control" house of identical floor plan located in the same development. On this 95°F day all demonstration house cooling energy use was consumed during off peak periods.
- As a result of the low air conditioning load, the 3.6 kW PV system installed on the Livermore house (also a Zero Energy Home demonstration) generated more electricity than the house consumed (Aug. 2002-July 2003).

Evaluation of Demand and Energy Savings

The calibrated DOE-2 model predicted an annual energy use that was within 5% of measured energy use for the Livermore house. Findings from analysis of the 3080 ft^2 Livermore house design in all sixteen climate zones were as follows:

- Non-diversified (i.e., end-use) demand reduction averaged 3.8 kW across all climate zones (weighted by construction volume) and was as high as 5.0 kW in some California zones.
- Annual utility bill savings under time-of-use (TOU) rates would exceed $250 in Climate Zones 8-15 and would exceed $450 in Climate Zones 13 and 15.
- In a production home scenario, estimated energy savings will more than offset incremental mortgage costs for ACC improvements in Climate Zones 2, 4, and 8-15 under time-of-use rates, producing a positive annual cash flow for homes built in these zones.
- Analysis results suggest that ACC design strategies and ventilation cooling can eliminate the need for compressor air conditioning in Climate Zones 1, 3, 4, 5, and 6. Depending on homeowner comfort demands and specific house design and orientation, there is also a potential to eliminate air conditioning in zones 2, 7, 8, and 16.

Other Outcomes

Other related outcomes from the demonstrations include:

- Inclusion of the NightBreeze system in a "zero net energy buyer" option package to be marketed by Centex Homes beginning of December of 2003.
- Widespread publicity, including both national and local television coverage, articles in *Home Energy* and *Discove*r magazines, papers, for technical societies and several newspaper articles.

- NightBreeze demonstrations planned by the Southern California Edison (SCE) utility company and for a DOE *Building America* project.
- Five NightBreeze systems installed in custom homes
- Initiation of two projects to expand NightBreeze ventilation cooling technology: one with the Energy Commission to develop products for gas furnaces, and one with DOE's Small Business Innovation Research (SBIR) program to expand NightBreeze technology for use in humid climates.

Conclusions & Recommendations

Proposed Goals vs. Accomplishments
The specific demand reduction and energy savings goals for Climate Zones 3 and 12 described in the project proposal were substantially achieved. The proposed goal of reducing peak load by 100% in Climate Zone 3 was verified by the Watsonville demonstration house, which maintained comfort without air conditioning. If homes are built using ACC principles, they should not require mechanical ventilation cooling in Climate Zone 3, though comfort would be improved. The 74% energy savings proposed for Climate Zone 3 could not be demonstrated because air conditioning energy use for the standard Clarum model built to Title 24 standards is almost non-existent. In retrospect, Climate Zones 2 or 4 would have been better subjects for demonstration of ACC design strategies in transition climates because they are slightly hotter on average.

A 50% demand reduction potential predicted by computer simulations indicated the proposed 37% peak load reduction goal for Climate Zone 12 could be exceeded. Monitoring results support this conclusion; air conditioner use showed that the Livermore house could have maintained comfort with a system that is 65% smaller than what is typically used in production homes. Compared to the proposed energy savings goal of 60% for Climate Zone 12, simulations predicted savings of about 45%.

This research has shown that these substantial demand reduction and energy savings can be accomplished while improving homeowner cash flow, particularly if time-of-use rates are applied. Energy savings exceed mortgage costs in most climate zones. The project has also shown that acceptance of ACC mechanical systems by production builders is a barrier for hydronic-based systems, but can be overcome through the use of systems that use furnaces.

Benefits to California

Technology, tools, and information developed under this project have the best opportunity to offer near-term reduction of peak load in production housing of any other known strategy. At the current construction rate of over 100,000 new single family residences per year, each year of production would eliminate the addition of about 280 MW of new load while saving ratepayers money on their utility bills. Energy demand offsets would reduce the need for new power plants and make utilities more profitable by avoiding the need to import expensive power during peak periods, while allowing them to build revenues during off-peak periods. Improved load factor and utility economics would help avoid future residential and commercial rate hikes, resulting in an overall benefit to California's economy. Energy savings would accrue at the rate of about 98 GWh per year, which translates into an accumulating reduction of carbon emissions at the rate of 5,500 tons per year (EPA 2002).

Recommendations

The state should move to insure that every new home is designed to reduce peak load (using ACC design principles) and mechanical ventilation cooling should be encouraged in most climate zones by CPUC-supported programs. Currently there is only one retrofit program for ventilation cooling (whole house fans), and there are no programs to encourage builders to construct homes to reduce peak load or air conditioner size. DOE has shown interest in supporting ventilation cooling in both their *Building America* and *Zero Energy Homes* programs.[1] Collaboration between these programs and state programs would boost the potential for rapid deployment.

Proposed Title 24 standards changes that include time-dependent valuation of energy may induce builders to pay more attention to load reducing strategies, but will not give credit to ventilation cooling. The Energy Commission should give strong consideration to including the ventilation cooling code change proposal submitted through PG&E for the 2005 standards into future rulemakings. This initiative should include modifications to alternative calculation methods to improve their accuracy in simulating indoor air temperatures. Perhaps the greatest value of implementing a Title 24 option would be that HERS raters would inspect systems to insure they are correctly installed.

The PIER program is already supporting development of a furnace-based ventilation cooling system that should begin to impact the market in 2004, and further advances should assist increased market penetration. Manufacturer interest in producing products that serve only the California or western markets could constrain the supply of equipment. The new PIER project will also be addressing this issue.

[1]The Building America web link is http://www.eere.energy.gov/building_america/. The link to the Zero Energy web site is http://www.eere.energy.gov.buildings/zeroenergy/.

Abstract

The multi-year Alternatives to Compressor Cooling (ACC) Project has the goal of reducing residential peak load in California by using nighttime ventilation to cool houses that are designed for optimal summer performance and that potentially eliminate the need for air conditioning in transition climates. This fifth phase of the project included the following primary objectives:

- Development of production-ready market acceptable hardware that facilitates ventilation cooling.
- Expansion of ACC designs to inland valley climates.
- Demonstration of ACC designs and systems in production homes.

Key accomplishments of the fifth phase were as follows:

- A production-ready HVAC system that integrates ventilation cooling with heating, air conditioning, and fresh air ventilation functions was developed and tested.
- Controls that also integrate these functions and provide feedback on the consequences of user settings that encourages use of ventilation cooling were designed and tested.
- Surveys, literature searches, and new research leading to the development of criteria for comfort in residential buildings were completed. These aided technology development and energy-use projections, and will support marketing efforts.
- A specialized DOE-2 computer model for simulating residential ventilation cooling was developed and then calibrated to actual monitoring data.
- A peak load reducing home suitable for California's warm inland valleys was designed and performance was evaluated.
- Two production homes in representative climate zones were built that incorporated ACC measures and one year of monitoring was completed.
- For the demonstration home built in the hotter California climate, there were 15 days with temperatures over 100°F between June and September 2003, but air conditioning was operated for less than a total of 9 hours during these months. Because the ACC design improvements were coupled with a grid-tied photovoltaic system, the owner has yet to be charged for electricity use.
- Peak load reduction and energy savings potential in all California climate zones was evaluated using a calibrated model.

Evaluations indicate that integration of ACC design principles into all new California homes would reduce non-diversified peak demand by a cumulative 266 MW per year and save a cumulative 98 GWh per year under current California construction trends. Evaluations also project that energy savings would offset incremental financing costs for ACC improvements in most of the warmer climate zones in the state. In summary, the

technology, tools, and information developed under this project provide an excellent opportunity for near-term reduction of peak load in new residential buildings.

1.0 Introduction

1.1 Background and Overview

In 1994 the California Institute for Energy Efficiency (CIEE) launched a project titled Alternatives to Compressor Cooling (ACC). The CIEE noted that it had become common practice for production homebuilders to install air conditioning in mild coastal-influenced "transition" climates where air conditioning is typically needed only a few days of the year. During "heat storms", or periods of high temperatures typically lasting 3-5 days, air conditioners in transition climates have nearly as much impact on peak load as air conditioners in hot climates. As a result, residential air conditioning currently accounts for about 45% of residential peak demand but only 7% of annual load (Coito 2003).

CIEE hypothesized that improved building envelope design combined with nighttime ventilation could eliminate air conditioner use, or shift most of it to off-peak periods. This cooling approach has promise in California, where many climate zones experience diurnal temperature swings of 30°F or more. This concept was demonstrated to be feasible through computer simulations completed using a DOE-2 model that was calibrated to a test building (Meldem 1995, Huang 1995 & 1999, Givoni 1998). Results from extensive computer simulations were used to map areas of California where compressor cooling can be eliminated or down-sized (Huang 1999, see also Appendix E). Research was also completed to identify sociological and health implications (Lutzenhiser 1994 & 1996, Wilcox 1997), and mechanical ventilation and control options were explored (Freitag 1998, Bourne 1998, Loisos 2000, Springer 2000). Research into market acceptability and identification of appropriate building and system design features were continued with the transfer of the project to the PIER program in 1999 (Loisos 1998 & 2000). This report describes research completed during the fifth phase of the project to develop and demonstrate ACC technology.

1.2 Project Objectives

The overall objective of this fifth project phase was essentially to advance ACC technology to the point of market readiness. We proposed to accomplish this objective by the following means:

- Developing, refining, testing, and demonstrating ventilation cooling hardware and controls that integrate with heating and air conditioning systems and are easy to install
- Preparing additional model building designs to extend the opportunity for reducing peak load to inland climates
- Conducting interviews to explore market receptivity and to gain information useful for designing user interfaces and control approaches
- Completing field studies and a literature review to expand on available information on human comfort in residential buildings for the purpose of identifying comfort acceptability, and adaptability to indoor temperature conditions that may result from the use of ventilation cooling

- Refining computer models for predicting ventilation cooling performance, including peak load reduction and energy savings, and impact on cooling equipment sizing
- Installing and testing the technology in production homes in Climate Zones 3 and 12 to verify peak load performance and to determine building industry and buyer acceptance and attitudes

Technical goals included reducing peak cooling loads by 100% and 37%, and achieving HVAC electrical energy savings of 74% and 60%, in Climate Zones 3 and 12 respectively. Economic objectives were to define installed costs for ventilation cooling, and other ACC measures that were identified in prior phases.[2]

1.3 Project Collaborators

Several subcontractors provided critical support to Davis Energy Group in the completion of this work. Key collaborators included:

- Loisos + Ubbelohde Associates: developed architectural designs, assisted with builder presentations, selection and modifications to demonstration homes, and managed the research on residential comfort.
- Bruce Hackett (with help from Bob McBride): conducted field surveys and interviews, contributed to the comfort research, and assisted with the design of the user interface.
- Loren Lutzenhiser (with Bruce Hackett): provided the sociological background for this work and contributed to comfort research.
- Joe Huang: created the special function required by DOE-2 to accurately model ventilation cooling.
- Pacific Gas & Electric Company (PG&E): completed testing on the damper and air handler.
- CR Communications: developed brochures, displays, and other marketing materials for the resulting "NightBreeze" ventilation cooling system.
- RCS/ZTECH: provided the control hardware and assisted with firmware development.
- Enviromaster International (EMI): fabricated and tested NightBreeze air handler production prototypes, and provided units for the demonstration homes.

Davis Energy Group staff who contributed to this project include David Springer, Leo Rainer, Marc Hoeschele, Bill Dakin, Dick Bourne, Jerry Best, Steve Brennan, Eric Heien, Ehern Wong, Vern Crawford, and Mark Berman.

[2] A list of measures applied to each demonstration house is included in Attachment 7.

1.4 Report Organization

This report describes work in the same sequence as the project tasks were ordered in the Statement of Work.

Section 1.0	Introduction
Section 2.0	Project Approach Section 2.0 describes the project approach, results, and minor outcomes. Because of the multiplicity of tasks and to improve reading continuity, intermediate results are also reported in Section 2.0.
Section 3.0	Project Outcomes Section 3.0 summarizes major results and project outcomes.
Section 4.0	Commercialization (Where Do We Go From Here?)
Section 5.0	Conclusions and Recommendations

Several of the project tasks are documented by reports that provide greater detail. These reports are included as attachments and are listed in the Table of Contents.

2.0 Project Approach

2.1 Development of Integrated Heating & Ventilation Cooling Unit

A substantial proportion of the project effort was dedicated to identifying and developing the hardware needed to facilitate ventilation cooling. If this hardware could integrate heating and air conditioning functions, then cost and difficulty of installation would be reduced, and market receptiveness would be vastly improved.

2.1.1 Air Handler Development & Testing

Although most residential heating and cooling systems utilize furnaces, a hot water air handler was chosen as the air-moving device because of its simplicity and minimal safety issues compared to furnaces. The energy and control advantages of using a variable speed electronically controlled motor (ECM) had been identified in prior project phases. Unlike permanent split capacitor motors used in most residential systems, ECM's operate at nearly the same efficiency over a wide range of speeds, making them highly suitable for such integrated applications. Other desirable features of an air handler included low internal static pressure loss, compact size, and capability of supplying up to about 60,000 Btuh of heating and 5 tons of cooling.

A variety of options for integrating an outside air damper with the air handler were reviewed, but it was determined that integrating the damper(s) would make the equipment too large to conveniently install in limited spaces. It was also determined that keeping the damper separate would lend more flexibility to installations, since it could be located close the source of outside air and connected by ducting to the air handler.

Air conditioners commonly use matched cooling coils that are added to the furnace or air handler. To reduce the amount of space required for the additional coil, a single dual function coil with both heating and cooling passages was designed. The coil included three rows of refrigerant fin-tubes, plus one row of heating fin-tubes. Though no coil design tools were available to test the theory, it was anticipated that the shared fins would improve efficiency of both the heating and cooling sections.

A survey of existing equipment identified no air handlers that met project needs, so the project team developed design specifications and drawings, and assembled an air handler using a purchased blower, an ECM motor, the coil described above, and a custom- fabricated cabinet. The air handler, pictured in Figure 1, also included a circulating pump and controls that are described in Section 2.2.

Figure 1. Prototype Air Handler

To test airflow delivery and coil performance, the air handler was delivered to PG&E's Technical and Environmental Services (TES) laboratory in San Ramon. TES used their airflow testing facility, which is designed to AMCA Standard 210-99 specifications, to measure airflow and fan power at a variety of external static pressures. TES also instrumented the air handler and measured heating and cooling delivery using a gas water heater and a 3-ton condensing unit as the heating and cooling source, respectively. Results of capacity tests, summarized in Table 1 and provided in Attachment 1, showed that the expected performance advantage of the dual function coil failed to materialize. As a result, the dual function coil was abandoned in favor of separate heating and cooling coils. Separate coils are also preferred since they allow greater flexibility in coil sizing.

Table 1. Prototype Air Handler Test Results

	Predicted, Btuh	Measured, Btuh
Heating Capacity	47,697	48,200
Total Cooling Capacity	28,957	22,306
Sensible Cooling Capacity	23,610	19,544

Tests also showed that the air handler delivered about 10% greater air volume than the projected 2000 CFM at 0.5″ external static pressure, and that airflow varied more than 20% over a 0 to 0.8″ static pressure range, suggesting motor programming could be improved. Fan power consumption was a very low 200 Watts at 1000 CFM and 500 Watts at 1500 CFM.

2.1.2 Fabrication of Air Handlers for Demonstrations

Subsequent to the development of the prototype air handler a manufacturing agreement was negotiated with Enviromaster International (EMI) to produce and market the NightBreeze system. EMI adapted one of their existing air handlers, substituting the ECM and NightBreeze controls for the conventional components. Following testing and motor programming, three units were produced for demonstration projects. Further information about EMI’s role in the project is provided in Section 3.6.

2.1.3 Damper Selection & Testing

The ideal outside air damper for use in ventilation cooling applications would connect the air intake of a furnace with the outside air source, while venting indoor air to outside, and be capable of handling up to 2000 CFM. This kind of operation is common to commercial economizers, but was not generally known to be available for split-system residential equipment. A reputation for poor reliability amongst commercial economizers also made immunity from failure a strong concern. A wide variety of damper possibilities were explored, including the use of separate motorized and barometric dampers, single and multi-blade types, and various drivers and linkages for operating them. Teamed with a local contractor, a Sacramento control manufacturer (ZTECH) had developed an economizer damper designed for residential use. The damper from their "SmartVent®" system, rendered in Figure 2, appeared to meet project requirements. With just one rotating blade that is direct coupled to a motor actuator, the damper has few moving parts. The single damper blade and well-designed seals minimize the potential for leakage. The damper is designed for mounting in the attic above the return air grille. Duct connections to an air handler or furnace and an outside air source are provided. A relief airflow path allows return air to be vented to the attic when the damper is in the open position.

A SmartVent® damper was procured, and tests were performed by the PG&E Technical and Environmental Services Laboratory (TES) to evaluate reliability, leakage, and resistance to airflow through its relief passage. For reliability testing the damper was configured to automatically cycle on a continuous basis and a counter recorded the number of cycles completed. Leakage was found to be 23 CFM (1.4% of fan flow) at 9 Pa, which is the typical pressure differential across a return air grille. Pressure tests led to the conclusion that a house with a specific leakage area of about 2 ft^2 would have a maximum indoor-outdoor pressure differential with the system operating and all windows closed of about 25 Pa. At this pressure it would require a maximum force of about 5 lbs. to open a 3’ wide door (manageable by most people). The damper was allowed to cycle open and closed over 10,000 times, during which no failures were occurred.

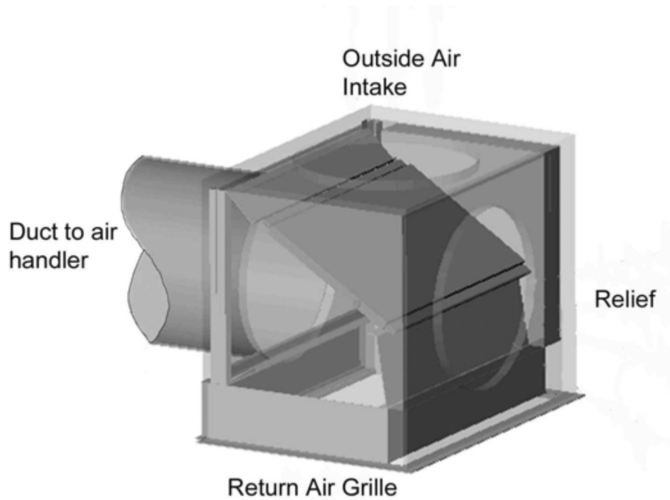

Figure 2. SmartVent® Damper

2.1.4 Documentation

A brochure was developed by subcontractor CR Communications to aid in marketing the ventilation cooling concept to builders and future buyers. An installation manual was developed to assist contractors with installation, and an operating guide was prepared for buyers of the demonstration homes. These are provided as Attachment 2.

2.2 Controls Development

Project experience taught us that correct use of controls is vital to the optimal use of ventilation cooling.[3] Many people find their thermostats too complicated and ignore programmed settings or use them improperly. Many also resort to the "off-auto" switch for control. We were concerned that adding features to already complicated devices would increase people's intimidation, so we devoted extensive efforts to making the control interface as simple and understandable as possible while accommodating the necessary flexibility to adapt to individual comfort preferences.

Though many people are accustomed to opening windows in the evening to cool their homes, most do not think about the physics involved. For example, most homeowners would not associate low morning indoor temperatures with reduced afternoon air conditioner use, nor would they readily understand the role of thermal mass as it relates to indoor temperature change and comfort. Also, controls that are not responsive to current conditions can result in overcooling on mild days, leading to temperature settings that do not enable ventilation cooling to work effectively on hot days. The concept of a graphical user interface that would encourage optimal use of ventilation cooling and thermal mass storage was developed in a prior project phase. This concept included a "comfort bar" to display the forecasted range of next day's indoor

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[3] Attachment 3 contains interviews of nine homeowners whose homes have SmartVent control systems.

temperatures, and to enable the user to view the consequences of adjusting both the indoor ventilation "low limit" and air conditioner temperature settings.

Controls development tasks included evaluation and refinement of the user interface design, selection of and modifications to control hardware, and final development and testing of firmware. This section reviews the control development process, describes control features that were selected, and provides results of tests and user feedback.

2.2.1 Hardware Selection

Functional requirements required that controls be flexible enough to integrate ventilation cooling with heating and air conditioning, be programmable, and include a graphical user interface and sufficient buttons to enable the user to enter the necessary settings. Requirements also included the capability to control an outside air damper and ECM as well as the heating and air conditioning system.

A review of available thermostats and control hardware identified only one platform appropriate for residential applications that could be programmed, that included provisions for an outdoor temperature sensor, that could control an ECM, and that had a user interface (thermostat) that could display the desired graphics. Developed as a prototype for a utility real time pricing pilot project by RCS of Rancho Cordova, California, the control system includes a wall display unit (WDU) and a controller. The WDU includes a 2″ x 4″ backlit LCD display and six buttons, the functions of which can be varied in software. The controller provided by RCS required the addition of a pulse width modulation (PWM) output for controlling the ECM and other modifications. Figure 3 shows the major control components and how they connect to other system components. The wall display unit is pictured in Figure 4. A 4-wire digital bus connects the controller to the WDU and outdoor temperature sensor. Microprocessors in both the wall display and the controller are programmed using imbedded C language.

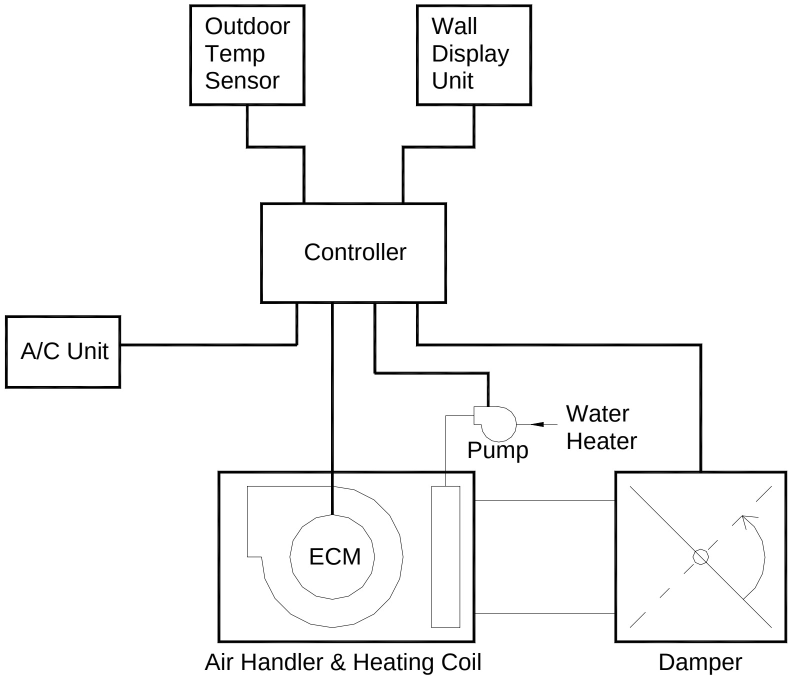

Figure 3. Control Components

Figure 4. Wall Display Unit

2.2.2 Firmware Development

Development and Implementation of Predictive Functions. In order to establish the amount of ventilation cooling needed to reduce or eliminate air conditioner use, it is necessary to predict indoor and outdoor temperature conditions for the coming day. The first step taken to develop predictive control algorithms was to compile a large database of temperature data. Sources included hourly data from monitoring projects DEG completed for PG&E and SMUD, DOE-2 weather files, and DOE-2 house simulations. The MINITAB® statistical package was used to test a large variety of possible predictive indicators and combinations of indicators, including daily average and max-min temperatures for preceding days, temperatures at various times of day, and temperature trends (rates of temperature change) taken at a variety of times. The best fit was obtained using a combination of minimum and maximum temperatures, temperature trends, and temperatures at discrete times from the prior two days. From these correlations, algorithms were developed for calculating next-day's predicted minimum and maximum indoor and outdoor temperatures. Results of these calculations are inputs to other calculations for setting the vent target temperature (indoor low limit) and ventilation airflow rate.

Optimizing Vent Cooling Control Variables. Ventilation cooling effectiveness varies with multiple parameters, including the ventilation rate. Higher ventilation rates will expend more fan energy but displace more air conditioner energy (see Figure 5). Some of the relationships between cooling demand, ventilation rate, and vent target temperature were intuitively developed, and it was not known whether these relationships were optimal.

With assistance from researcher Joe Huang, a special function was developed for DOE-2E that included the same predictive functions that were developed for the control. Equation constants were parameterized in DOE-2 to identify those that would yield the lowest combined ventilation fan and air conditioning energy use. This analysis used the 1860 ft^2 "Inland Valley House" model (see Section 1.2). The results showed that a ventilation rate of about 0.6 CFM per square foot yielded the lowest combination of fan and compressor energy use for most California climate zones. Figure 5 shows these results for Climate Zone 12 (Northern California Central Valley). Other analyses verified that the intuitively derived constants yielded the optimum cooling effectiveness, and that the sensitivity to changes in these parameters is relatively small.

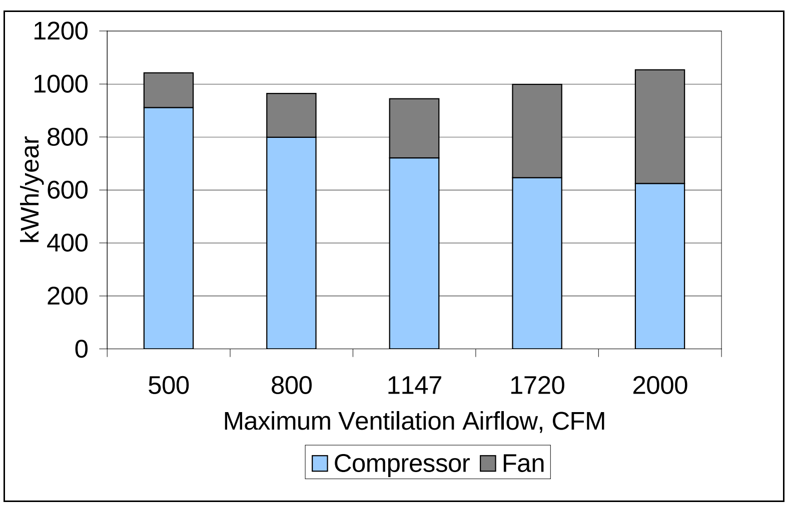

Figure 5. Cooling Energy Use vs. Maximum Airflow (Climate Zone 12)

Air Conditioner Pre-cooling. Typical "heat storms" in California are generally accompanied by relatively warm nighttime temperatures that preclude ventilation cooling, and consist of three to five days with daytime temperatures that exceed 100°F. In addition to optimizing ventilation cooling parameters, we investigated whether peak load reduction could be achieved by running the air conditioner in the morning hours to cool building mass on days when nighttime temperatures do not fall sufficiently to permit ventilation cooling.

Using the same DOE-2 model that was used for control optimization, cooling energy use was calculated for four cases in two climate zones. Base cases were run to establish energy use and costs using both the standard tiered (E-1) PG&E electric rate, and the time-of-use (E-7) rate, which has a noon–to-6PM weekday on-peak period (see Appendix A for rate information). A conventional air conditioner with a fixed morning setback of 74°F, and a NightBreeze system with a calculated setback based on the vent target temperature were also simulated. Results shown in Table 2 indicate an increase in total cooling energy for the conventional system but over $100 savings due to the time-of-use rates. The NightBreeze system with the pre-cooling function is projected to save two to three times more due to greater pre-cooling and substitution of efficient mechanical ventilation for compressor operation.

Table 2. Effect of Building Pre-cooling on Peak Load and Cooling System Operating Cost

Analysis Case	HVAC Energy Use (kWh) Total	On-Peak	Off-Peak	Total Cost/year Electric	Cost Savings
Sacramento (CZ 12)					
Base Case (E-1 Rate)	1,607	-	-	$ 916	-
Base Case (E-7 Rate)	1,607	649	958	$ 877	$ 39
Conventional A/C* (E-7)	1,951	164	1,786	$806	$ 110
NightBreeze (E-7)	729	53	676	$637	$ 279
Fresno (CZ13)					
Base Case (E-1 Rate)	4,103	-	-	$1,418	-
Base Case (E-7 Rate)	4,103	1,528	2,575	$1,459	($ 41)
Conventional A/C* (E-7)	4,397	563	3,835	$1,278	$ 140
NightBreeze (E-7)	2,775	273	2,502	$ 983	$ 435

*Conventional air conditioning system with thermostat set to 74°F between 6AM and 12PM.

Fresh Air Ventilation. Reduced building air leakage resulting from improvements in construction practice has prompted changes to ASHRAE Standard 62 that will make mechanical ventilation mandatory, as it currently is under Title 24 standards when credits are taken for tight envelope construction. The ability of the ECM-powered fan to deliver specific air volumes coupled with damper control facilitates nearly exact compliance with fresh air ventilation requirements. This feature was included in NightBreeze control functions.

Human Factors Evaluation of the User Interface Design. Since about 1998 Beutler Corporation, a leading Sacramento area HVAC contractor, had been installing a residential economizer system called SmartVent.[4] Prior to finalizing the design of the

[4] More information at http://www.beutlerhvac.com/smart_vent.htm.

user interface we exploited the opportunity to interview SmartVent homeowners about their experiences with it, and to obtain their impressions of the prototype NightBreeze wall display unit (WDU). Before finalizing the WDU design we also installed NightBreeze controllers in two homes that had SmartVent® systems and interviewed these homeowners after they had about two months of experience with the new control. Results from these nine interviews were used to refine menu access and 'help' instructions, verified that NightBreeze improvements were generally on the right track, and showed remarkable differences in how people understand and interact with their thermostats and in their comfort preferences. A report on these interviews is provided in Attachment 3.

To obtain further feedback on the WDU, we developed a "virtual" WDU and posted it to a web page that included a response form. Using the Web site, reviewers could manipulate the buttons using their mouse to explore the menu structure, modify settings, and explore help instructions. The site also provided an accelerated one-day simulation of system performance so reviewers could observe the consequences of their settings. Twenty-five survey responses were completed and results were factored into improvements in the display design. These survey responses are also provided in Attachment 3.

2.2.3 Description of Control Functions

Program Code and Location. All control programming, including code for the wall display unit and for the controller, was developed in C language. Separate source code was required for the wall display unit and for the main controller microprocessors. The wall display unit microprocessor and memory chip contains programming for display graphics and input/output functions. User settings, clock settings, and program logic are stored in the controller's microprocessor and memory.

Primary Control Functions. Using concepts developed in the current and prior project phases, a functional specification for the controls was developed that defined the appearance of the user interface, inputs, outputs, and control algorithms. Attachment 4 includes a complete description of WDU menus and functions. A brief description of the primary control functions follows.

The control was programmed to present four operating modes to the user via the WDU shown in Figure 4:

- **Cooling:** In cooling mode the control operates the system to provide nighttime ventilation cooling, and runs the air conditioner if needed to maintain user thermostat settings. Two temperature settings are selected in cooling mode using the wall display unit. Figure 6 shows the screen graphic. The "Hi" setting establishes the maximum desired indoor temperature and is also the temperature setting for air conditioning. The "Low" setting allows the user to specify the lowest temperature to which the house will be ventilated at night. The wall display unit used for making these settings is shown in Figure 5. The shaded area on the horizontal bar represents the next day's predicted indoor temperature range; this "comfort bar" is explained in greater detail below.

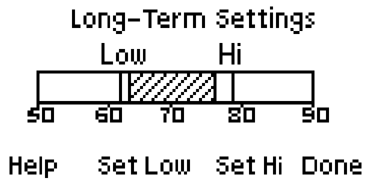

Figure 6. Cooling Settings Screen

The peak load reduction strategy implicit in control functions is to cool the house to the lowest temperature that comfort requirements will allow by morning and to let the temperature float upward during the day. For this reason the WDU includes no provision for scheduling air conditioner setpoints. A "short term" setting allows temporary override of the "Hi" setting for a selectable length of time.[5]

- **Heating:** In heating mode the control turns on the hot water circulating pump and runs the fan at a speed proportional to the difference between the indoor temperature and the thermostat setting. The objective of this strategy is to reduce fan energy use and system noise during low-load heating cycles. In heating mode the control also operates the system to deliver a prescribed amount of fresh air to the house, preheating outdoor air as needed. Eight heating schedules were programmed that include four weekday and four weekend periods. To simplify temperature settings and provide a quick view of current settings, a time/temperature graph was developed. Separate weekend and weekday graphs displays weekend and weekday schedules so that all temperature settings can be seen in one view, as shown in Figure 7.

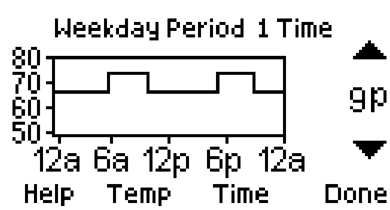

Figure 7. Temperature Schedule Screen

- **Vacation**: Vacation mode is similar to cooling mode, except that the heating system will operate if the indoor temperature falls below the temperature setting. The user sets both high and low temperature limits and the system will maintain the indoor temperature within those limits using ventilation cooling, but not compressor cooling, to the maximum extent possible.
- **Off:** All system functions are disabled in Off mode. From this mode clock settings can be modified and an "advanced settings" menu can be accessed. The advanced settings are intended for the installer to establish airflow for each mode, to calibrate temperature sensors, and for other system settings.

[5] Through interviews we determined that people have a tendency to lower summer thermostat settings when they have visitors.

Manual Fan and Temperature Override. A fan button allows manual operation of the fan in any of the modes, either to recirculate air or to ventilate with outside air. Override buttons provide for "short term" temperature settings (heating or air conditioning) for a length of time specified by the user.

Ventilation Cooling Functions. The control is designed to initiate ventilation with outside air as soon as the outdoor temperature falls below the indoor temperature. Since heat is added to ventilation air as a result of attic duct heat gain and fan motor heat, ventilation actually does not commence until the outdoor temperature falls below the indoor temperature by about 5 deg. F (user selectable). To prevent overcooling, ventilation is discontinued when a minimum indoor temperature (vent target) is reached. This target temperature is equal to the "low" setting on very hot days, but is automatically raised on mild or cool days to prevent overcooling.

Control logic includes functions that predict the next day's indoor and outdoor temperature conditions based on previous day's weather. For purposes of control, these predictions are used to vary both the vent target temperature and the ventilation rate so as to prevent overcooling and to reduce fan energy consumption. With a fixed low limit temperature (or vent target temperature), users would be inclined to select a setting that would assure comfort on mild days, thus missing the opportunity to cool the house to as low a temperature as possible on hot days. By allowing the vent target temperature to drift upward during mild weather, control behavior gives the user confidence that a low setting will not produce uncomfortably cool indoor temperatures. Varying fan speed and airflow rate with weather conditions has a similar effect on comfort, and also reduces fan energy use. Stated another way, the objective of this control logic is to apply just enough ventilation cooling to keep the indoor temperature below the air conditioner set point.

Temperature predictions also help the user make informed decisions about temperature settings by providing feedback on the consequences of those settings. The shaded "comfort bar" shown in Figure 4 displays the range of indoor temperatures that should be expected for the next day given the low and high temperature settings selected by the user. Lowering the "low" setting will shift the comfort bar to the left until the point is reached that it will not move further because nighttime low temperatures cannot cool the house more, or because the house would be overcooled. Thus this feature allows selection of a practical setting that is consistent with the user's comfort preferences.

The comfort bar also provides a clear indication as to whether the air conditioner is likely to run the next day. If the comfort bar (next day's predicted indoor temperature range) extends beyond the thermostat setting for the air conditioner (the "Hi" setting), then the message "A/C will run" will be displayed on the screen to make it obvious what the consequences of the current settings are likely to be. This display feature provides those homeowners who are inclined to avoid using their air conditioners with a means of selecting temperature settings that achieve this goal within their limitations of acceptable comfort.

2.2.4 Control Tests

Following basic debugging, control firmware was tested in the laboratory and in the field. A small environmental chamber was used to simulate outdoor conditions, and control outputs were monitored. Preliminary tests were also conducted at two homes that had previously installed SmartVent® systems used with furnaces (see Section 2.2.2). The first field tests of the controls with a variable speed air handler were completed at the home of the principal investigator, and another variable speed air handler system was retrofitted to the home of a PG&E employee. Numerous improvements were made on the basis of these tests over a two-year period.

2.3 Extending the Design to Inland Climates

The name of this task is somewhat of a misnomer in that it covered a much broader scope than the title suggests. Work completed under this task was market oriented, but its discoveries also contributed significantly to technical efforts. Goals of this task were to:

- Develop "inland climate" house designs for which the objective is air conditioner size reduction rather than elimination
- Estimate inland climate house performance using computer simulations
- Identify homeowner behavioral patterns and attitudes, and establish a base of understanding of residential comfort to support product development, understand markets, and develop accurate energy savings estimates

2.3.1 Inland Valley House Design

One of the keys to overcoming reluctance of builders to participate in the development of compressorless homes (homes without air conditioners) is to demonstrate that this can be accomplished using design methods and technologies that are readily available to them. Builders also must be assured that these homes appear similar to models they are currently building and successfully marketing.

Prior project phases developed home designs for coastal climates where elimination of air conditioning is feasible. For the current project phase, team member Loisos + Ubbelohde Associates studied Central Valley production home offerings from several builders and developed an 1860 ft^2 design that suited both the architectural and climatic conditions of the valley. An elevation is shown in Figure 8; other views and a list of included efficiency measures are provided in Attachment 5. The design was developed to perform well in all orientations; builders routinely use the same plan on lots with differing exposures. Windows are positioned such that performance penalties from solar gain are not significantly greater in any of the four cardinal orientations. The Loisos + Ubbelohde plan was offered to two builders who participated in demonstrations (see Section 2.3).[6]

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[6]Both builders were positively influenced by the design, but both had already developed models that integrated with the rest of their inventory and fit their lot sizes.

Figure 8. Elevation of "Inland Valley" House Design

2.3.2 Inland Valley House Analysis

The DOE-2.1E model with special function described in Section 2.2.2 was used to simulate performance of the Inland Valley House design in six representative California climate zones. (A list of climate zones, their descriptions, and a map showing these zones is provided in Appendix B). Features that distinguish the house from standard production homes include an attic radiant barrier, low-E^2 windows that are shaded by architectural features, slab perimeter insulation, thick (5/8") drywall and 50% exposed slab floor surfaces for thermal mass, and ventilation cooling.

An important discovery gained from this work was that, in comparison with data from a large sample of monitored homes, DOE-2 predicts much lower indoor temperatures when using natural ventilation (open windows) only. Reducing natural ventilation area to 2.5% of window area resulted in less than a 1°F discrepancy between modeled and monitored indoor temperature, and this window area was used to produce simulation results for natural ventilation. Another finding was that while judicious use of windows for ventilation cooling dilutes the energy savings value of mechanical ventilation cooling, mechanical ventilation still significantly reduces energy use during peak periods.

To identify the individual contributions of building envelope improvements and ventilation cooling to building performance, a version of the house that conforms to California Title 24 energy standards was also modeled and used as a baseline. Figures 9 through 12 display the results of this analysis in terms of the cumulative percentage improvement due to both envelope design and ventilation cooling. Figure 9 and Figure 10 compare energy savings during on-peak periods and Figure 11 and Figure 12 compare energy savings during all periods. Figures 9 and Figure 11 were developed using base cases with no natural ventilation, and Figure 10 and Figure 12 include natural ventilation in the base case. The upper portions of the bars represent the incremental increase in performance resulting from mechanical ventilation.

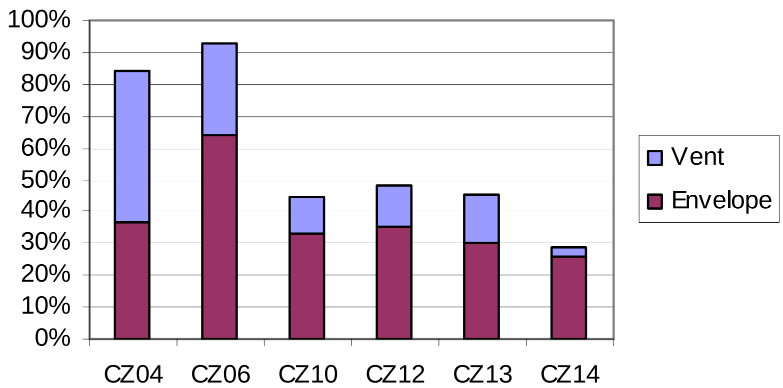

Figure 9. Peak Demand Reduction without Natural Ventilation

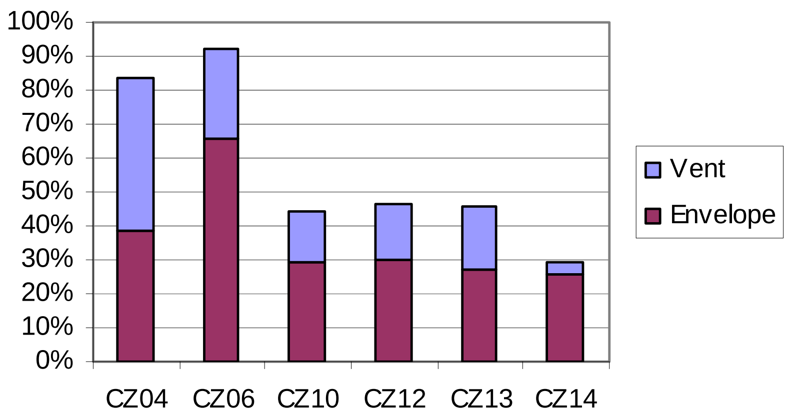

Figure 10. Peak Demand Reduction with Natural Ventilation

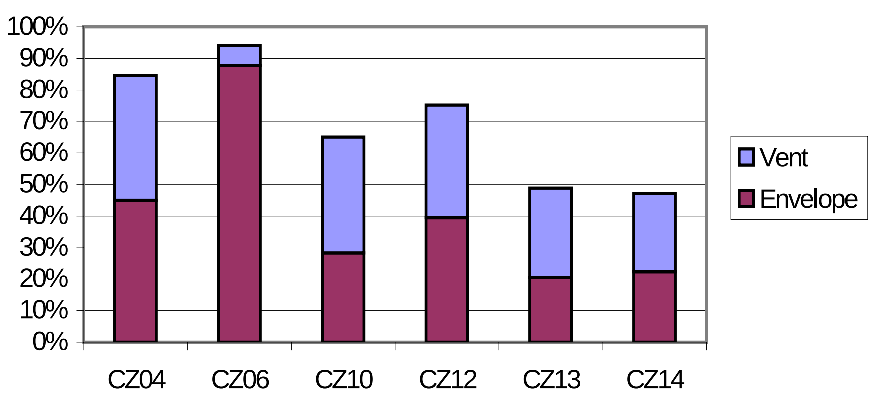

Figure 11. Total Energy Savings without Natural Ventilation

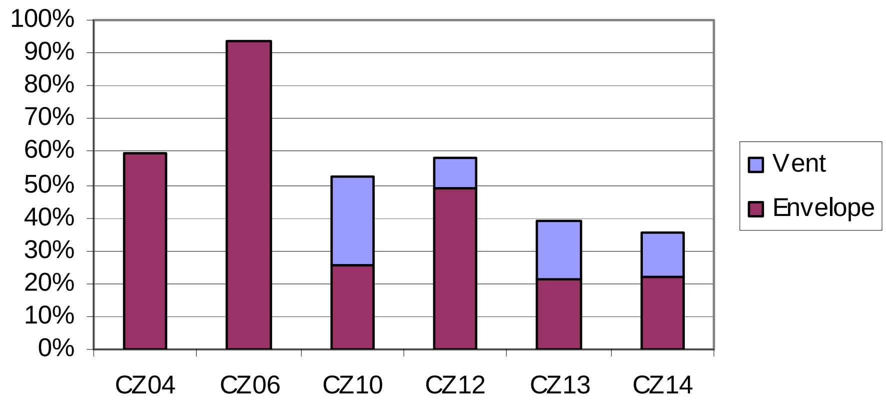

Figure 12. Total Energy Savings with Natural Ventilation

Simulations show there are no energy savings in Climate Zones 4 and 6 if windows are used for ventilation because the combination of natural ventilation and the improved envelope nearly eliminate all air conditioning operation in these mild climates. Therefore, operating a ventilation fan increases energy use in these cases. The hottest zones (CZ13 and CZ14) show smaller percentage savings, although the annual operating cost savings are highest.

If the Inland Valley House design features reduce peak load, then it should also be possible to reduce air conditioner size. Table 3, which was developed using DOE-2 predictions of maximum cooling and typical air conditioner sensible cooling capacities, lists air conditioner sizes for each of the analysis cases. Inland House sizing was based on no use of natural ventilation, which is considered typical for most residences. This analysis suggests that up to a 1½ ton reduction in size is made possible by applying all of the Inland House design features, and that ventilation cooling is responsible for a half-ton size reduction in three of the climate zones. Complete results of this analysis are included in Attachment 5.

Table 3. Air Conditioner Sizing Comparison

Climate Zone	Baseline (kBtuh)	Inland House (kBtuh)	Inland House With Mechanical Ventilation (kBtuh)
4	24	18	-
6	30	18	-
10	30	24	18
12	30	24	18
13	36	24	18
14	30	24	24

2.3.3 Comfort Surveys and Criteria for Residential Comfort

Though much research has been completed to develop an understanding of comfort in commercial building settings, little is known about the variety of comfort perceptions of people in residential environments. Two tasks were completed to gain a better understanding of residential comfort. The first was a detailed field study that included interviews of 50 homeowners living in Davis, California and Gold River (suburban Sacramento). These interviews were completed by project team members Bruce Hackett and Robert McBride and are reported in Attachment 3. Under the second task, Loisos + Ubbelhohde, assisted by Loren Lutzenhiser and Bruce Hackett, produced a report on their studies of comfort in the residential environment. This seminal work includes an extensive literature search and review, an evaluation of comfort definitions, and a review of ACC design characteristics that are likely to affect comfort. The report also proposes an advanced comfort criteria for houses designed using ACC principles, and is provided in Attachment 6.

One of the objectives of the survey was to identify the range of preferred temperatures, and to determine whether lower morning temperatures that are a necessary feature of ventilation cooling would be acceptable. Table 4 lists responses to survey questions regarding what minimum and maximum temperatures are preferred (ideal) and what temperatures are tolerable. Both groups interviewed find 65°F to be a tolerable morning low temperature.[7] Given the social homogeneity of the populations studied, there appears to be a considerable spread and a large amount of variation in the preferred and tolerable temperatures.

Table 4. Temperature Preferences of Survey Respondents

Temperature	Davis		Gold River	
Preference	Mean	Range	Mean	Range
Low Ideal	69.8	60-79	75.2	65-80
High Ideal	78.6	72-90	78.0	75-82
Low Tolerable	65.2	50-78	63.6	55-75
High Tolerable	83.6	78-98	82.4	77-90

One interesting finding of the survey, as stated by Bruce Hackett, is that "There is … a virtually routine and almost predictable division of thermal preferences -- sometimes acrimonious -- even within households; in almost every case spouses' preferences were not the same, with the men twice as likely as the women to prefer it cooler than their partner." This phenomenon can lead to "thermostat wars" which result in considerable tampering with thermostat settings, the consequence of which can only be determined through an extensive survey of ventilation cooling system owners.

Another observation contributed by Bruce Hackett is that "…opening the house at night is not only an underutilized cooling resource but also an 'occasional' rather then regular

[7] Computer simulation studies, including those described in Section 2.2.3, used a "low" setting of 65°F.

or systematic activity on the part of most of those who do it." Concern over security induces people to only open upper floor windows, and neighborhood noise prompts some to leave windows closed entirely. Benefits of mechanical ventilation are enhanced in these circumstances. The reader is encouraged to explore the many other interesting findings described in Attachment 3.

The Loisos + Ubbelohde report brings into question the application of ASHRAE Standard 55 to residential comfort, and discusses adaptive comfort models being proposed under Standard 55-1992R. As quoted of Bruce Hackett in the report, "…the experience of comfort is mediated by who one 'is' and what one is doing, and this means a movement away from homogeneity toward diversity - people aren't all the same, the experience of comfort changes over time via 'adaptation', and comfort is 'situational' (meaning, e.g., that comfort chambers tell us about comfort in comfort chambers)."

As also pointed out in the report, it is possible to attain comfortable conditions by combining all the thermal comfort variables in sum total, for example, delivering a low air temperature to try to balance out disproportionate levels of mean radiant temperature, lack of air movement, humidity, clothing and metabolic rates. However, attaining comfort is far easier if ALL variables individually stay within prescribed limits. This is why insulated houses are more comfortable than non-insulated houses, why double-glazing is more comfortable during winter nights than monolithic glass irrespective of furnace size. Keeping all variables within limits can explain how some buildings maintain near universal comfort (very low complaints) under extreme conditions better than others do.

Comfort criteria proposed by Loisos + Ubbelohde include: (1) an ideal set of boundaries (the Adaptive Comfort Standard) and (2) a set operational conditions that facilitate successful adaptive actions on the part of the occupants. If the house interior exceeds the thermal conditions defined in the Adaptive Comfort Standard, the occupants must have the possibility of achieving comfort in two fundamental ways: through any combination of adaptive activities that the house design and their social context support, or by using the mechanical system to bring the interior conditions within the boundaries of the ACS.

Criteria 1: The house should attempt to provide conditions defined as 80% acceptability limits in the ASHRAE Standard 55 Adaptive Comfort Standard (operative temperature ranges specified in Figure 5.3.1 of that document).

Criteria 2: If the house cannot achieve the levels of comfort defined in the ACS, the occupant must have *both* of the following options.

Option 1: Adaptive Actions. The following adaptive actions are to be available to the occupant and operable under the occupant's choice and control:

- **Change of location to a more desirable set of thermal conditions**. For example, migrate to a cooler space in the summer, a warmer space in the winter. This implies that a variety of thermal conditions are available within the house and yard.

- **Change the velocity of air movement**. For example, turn on a ceiling fan or open a window.
- **Change the MRT for the following day**. For example, if night ventilation has not cooled the house sufficiently, change the program to decrease the acceptable morning temperature.

Option 2: Mechanical Control. There will likely be infrequent periods that the adaptive actions cannot or do not function to achieve comfort for the occupant. This can be due to exterior conditions and/or circumstantial restraints. The house must therefore also have the capacity to achieve the ACS through mechanical means.

Loisos + Ubbelohde argue that lower temperatures due to night ventilation are likely to be considered acceptable to residents on three grounds. First, lower temperatures are easily adapted to through bed covers. Even when the indoor air temperature is strictly maintained, comfort varies through the sleeping hours: as the residual body heat of the previous day's activity is lost, adjustment by gradually adding bedcovers is needed. In a night ventilation scheme, the change in covers may be greater as the air temperature drops, but in either case (constant temperature or night ventilation) an adjustment of covers is required. Once required, the magnitude of that adjustment is of little consequence. Second, residents will understand and appreciate the results involved in a predictable pattern of lowering the indoor temperature in preparation for the heat of the following day. Third, the pattern of enjoying the coolness of the night in contrast to the heat of the day is strongly etched culturally and physiologically in those areas where there is a significant diurnal swing and low humidity.

2.4 Field Testing, Monitoring & Analysis

The prime objectives of Task 2.4 were to test the extent to which homes built to "summer comfort" specifications would have reduced peak cooling loads, and how well owners would accommodate ventilation cooling. Other objectives included evaluating the acceptability of the NightBreeze system to production homebuilders and buyers, obtaining owners' reactions to comfort and ease of use, and developing performance data that could be used for calibration of simulation models.

2.4.1 Selection of Demonstration Homes

Our intention was to demonstrate summer comfort homes in two locations, coastal-influenced Climate Zone 3, where air conditioning is not needed but sometimes installed, and Climate Zone 12 (Northern California central valley), where air conditioning is commonly used. These locations were selected to provide examples of the elimination of air conditioning (Climate Zone 3), and significant peak load reduction (Climate Zone 12).

In prior project phases the ACC team had established and coordinated a "summer comfort" category for the Pacific Coast Builders' Conference Gold Nugget Award program. Experience from this effort taught us that builders were generally not taking energy efficiency seriously at that time. We were therefore not optimistic at the prospect of finding production builders who would be interested in participating in a demonstration, and for this reason set aside $35,000 of the project budget for builder incentives. A list of production builders was compiled and contacts resulted in presentations to three national builders, Pulte Homes, Del Webb, and Centex Homes, and one California builder, Clarum Homes. Based on their level of enthusiasm for the project, development locations, and construction timing, Centex and Clarum were selected and both agreed to participate.

The Centex demonstration is located in their Los Olivos development in Livermore. This development includes 94 single-family homes comprised of five floor plans. Project timing was such that the model homes could not be used for the demonstration, so one of the "for sale" units, a single-story 3080 ft^2 plan, was chosen as the ACC demonstration site. Centex agreed to leave the house open for tour for one month, after which it was placed on the market. It sold in September 2002 and was occupied in October.

Clarum Homes opted to use one of their models for the demonstration, which is a two-story 1611 ft^2 plan. The model is located in the 31-unit Cherry Blossom development in Watsonville. The house was completed in September 2001, but was not sold and occupied until May 2002. Photos of the houses are provided in Figure 13 and Figure 14 and Appendix C.

Both houses became demonstrations of renewable energy as well as efficiency. The Livermore house was used as a Zero Energy Homes program pilot project, as well as a prototype for Alameda County's green building guidelines.[8] All of the homes in the Clarum Cherry Blossom development were equipped with photovoltaic systems.

2.4.2 Home Designs and Features

Demonstration project agreements required builders to include specific measures to improve summer performance, which varied slightly with climate. These design upgrade measures are listed in Table 5. Both builders installed high performance windows as standard equipment. To insure efficient heating operation, high efficiency water heaters were installed at each of the houses to provide hot water for both domestic use and space heating. Water heater types are listed with the other measures in Table 5. The Livermore house received a solar water heater as one of its Zero Energy Homes design features. This house, built by Centex Homes, also included multiple measures that were added to meet green building guidelines, including:

- Wet spray cellulose wall insulation
- Fly ash concrete
- Engineered wood headers and joists
- Bamboo flooring
- Fluorescent lighting

[8] See www.stopwaste.org/nhguide.html for information on Alameda County's green building guidelines.

Figure 13. Centex Demonstration Home (Los Olivos, Livermore, CA)

Figure 14. Clarum Demonstration Home (Cherry Blossom, Watsonville, CA)

Table 5. Summer Performance Design Upgrades

Centex - Los Olivos, Livermore	Clarum - Cherry Blossom, Watsonville
Attic radiant barrier sheathing	Attic radiant barrier sheathing
> 50% hard surface floor	> 50% hard surface floor
5/8” drywall, all walls and ceilings	5/8” drywall, all walls and ceilings
R-10 slab perimeter insulation*	NightBreeze ventilation cooling system
Trellises over east and south windows*	Polaris condensing gas storage water heater
NightBreeze ventilation cooling system	
Rinnai instantaneous water heater	

*These measures were not included in computer simulation results described in Section 2.4.6. See footnote #9.

2.4.3 NightBreeze System Installation and Commissioning

NightBreeze systems at both sites were installed by the builder’s HVAC contractors. Before construction was initiated we met with HVAC and plumbing contractors at both sites to review installation requirements, schedules for delivery of systems, and other details. Neither HVAC contractor expressed concern about their ability to install the systems, but both were concerned about warranty and service issues.

The original HVAC design for the Livermore demonstration house called for installation of two attic-mounted furnaces and two condensing units to separately serve the living areas and the bedrooms. The design for this plan was later modified to a single furnace with two-zones. Since the NightBreeze system was not capable of serving two zones, it was necessary to install two complete systems.[9] Both the air handlers and the dampers were installed in the attic. Double louvers were fitted to the north side gable to provide a source of outside air (see the lower vent in Figure 15), and outside air sensors were mounted just below the louvers. Side-by-side two-ton condensing units on the south side of the house were connected to 4-ton cooling coils located at the air handlers.[10] The plumbing contractor for Centex was challenged by the complexity of the piping, which included connections to both air handlers, plumbing between the solar and gas water heater, and a hot water recirculation system. We assisted by providing detailed drawings and a layout of the pipe stub-out locations.

The HVAC design for the Watsonville house included a furnace located in the garage, and attic supply and return ducts. The builder did not install air conditioning at any of the Cherry Blossom units, but provided line sets and wiring so that owners could easily retrofit them. Return air was ducted from the attic-mounted outside air damper to the

[9] Another PIER project (Contract No. 500-020026) was initiated in 1993 to develop a multi-zone version of NightBreeze to reduce the cost of systems installed in homes with more than one zone, and also to develop a furnace-based version.

[10] Despite the small cooling loads, 4 ton coils are needed to minimize pressure drop for ventilation cooling since all air passes through the coils.

furnace in the garage. Rather than install an intake grille in the gable as was done at the Livermore house, outside air was ducted vertically through the roof. We designed and fabricated a special vent cap to cover the outside air intake, which also housed the outdoor temperature sensor. The vent cap is pictured in Figure 16.

Periodic inspections were conducted during construction to insure that the measures listed in Table 5 were properly installed. After completion of construction the mechanical systems were commissioned by setting airflow rates, temperatures, and other control settings; verifying proper operation of sensors, fans, dampers, and pumps; and installing filters. Damper motors at both sites were damaged during construction and it was necessary to replace them.[11] Wiring of the pumps serving the air handlers was reversed at the Livermore site, but no other problems were observed during commissioning. To provide data that would be used for monitoring airflow and cooling delivery, tests were conducted at both sites to correlate motor CFM (a monitored parameter) and airflow.

Figure 15. Outside Air Intake Louver, Livermore House

Figure 16. Outside Air Intake Vent Cap, Watsonville House

[11] Damage occurred despite prominent labeling. A recommendation was added to the installation manual that damper assemblies be removed from the return air boxes until the finish construction phase.

2.4.4 Incremental Costs of Construction

The builders of the two demonstration homes were interviewed to identify the incremental cost to make the improvements that are listed in Table 3. Net costs were estimated at $6,820 for the Watsonville house, and $17,500 for the Livermore house. Livermore costs were dominated by the high cost of the added trellis ($8,830) and the slab perimeter insulation ($2,570). For both homes the substitution of high efficiency water heaters also contributed significantly to the cost. Subcontractor costs for installing the NightBreeze systems seemed high, and likely would have been significantly lower if the systems had been installed in more than one home, and if the subcontractors had been required to bid on them instead of treating them as an "extra". Construction process reports that include detailed cost information are provided in Attachment 7.

2.4.5 Monitoring

Objectives and Approach. The primary objective of monitoring was to determine whether computer simulations previously completed were producing realistic results in terms of load reduction and energy savings. The project plan called for using the monitoring data to calibrate a computer model, and to use the model to compare ACC house performance to the base case. This approach eliminates questions about differences in occupant behavior that arise when monitoring and comparing the performance of two houses, one incorporating ACC measures and the other that serves as a "control". The calibrated modeling approach also allows extrapolation of results to other climate zones. This plan was carried out, but an opportunity to perform simple monitoring on a "control" house with an identical floor plan arose late in the project. Both efforts yielded useful results.

Another objective, also important to this study, was to observe how homeowners interact with the NightBreeze controls, and how they operate their homes in general. This information is useful for making further refinements to the user interface and improving written instructions. A final objective, which could be classified as "continuous commissioning", was to observe operation of the NightBreeze system to identify any problems with components or controls.

Monitoring Plans. Monitoring plans were prepared for the two demonstration houses and are included in Attachment 8. Data collected from the sites included indoor temperature, supply and return air temperature, fan and pump energy, outside air damper status, and fan RPM,[12] which was used to calculate airflow. Both outdoor temperature and horizontal solar radiation were also measured to provide for normalization of data. Air conditioner energy was only measured at the Livermore site since no air conditioning was installed at Watsonville.

Monitoring of the Livermore site was more complex due to the dual NightBreeze systems, the presence of air conditioners, and the need to collect more detailed data for the Zero Energy Homes project. Monitoring points were added to measure heat

[12] The ECM motor includes a provision for pulse output that is proportional to motor RPM.

delivered by the solar water heater and by the gas water heater for domestic and space heating use. Gas consumption by the instantaneous water heater was also measured.

Each house was equipped with dataloggers (Livermore required two) and modems connected to dedicated telephone lines. A computer located at the Davis Energy Group office automatically dialed the modems, downloaded the data, and reported out-of-range or missing data on a daily basis. A summary of monitoring results is also included in Attachment 8. With support from the Zero Energy project, data from the Livermore site were also transferred to an FTP site from which Florida Solar Energy Center downloaded the data for posting on their Web site.[13]

The "control" house described above was equipped with "Hobo" dataloggers in June of 2003. These recorded the indoor temperature at each of the two thermostats, attic temperature, and air conditioner and furnace fan status. Status data were converted to power consumption values by assuming that the combined fan and compressor demand was 5 kW for the 5 ton cooling system. Difficulties with these loggers resulted in partial data loss, but results of this monitoring proved to be quite revealing.

Watsonville Site Monitoring Summary. Monitoring commenced at the Watsonville site in October 2001. The house was used as a model home and was otherwise unoccupied until May 2002 when the house was sold. Monitoring continued until May 2003 when the equipment was removed.

Watsonville proved to be too mild a climate to serve as a rigorous test of ventilation cooling. Compounding this, the buyer rarely turned on the system for either cooling or heating, preferring to let the indoor temperature drift. The combination of mild climate, improved building envelope, and the owner's tolerance for temperature extremes eliminated any need for cooling. The highest indoor temperature recorded when ventilation cooling was in use was 78°F, and the highest overall indoor temperature was 82°F. Figure 17 plots temperatures and fan power during a "hot spell" in September 2002. Due to control settings the fan was delivering a maximum ventilation rate of about 430 CFM while drawing less than 50 Watts of power. The highest HVAC system demand for the summer of 2002 was a mere 56 Watts.

[13] http://www.fsec.ucf.edu/bldg/active/zeh/livermore/index.htm

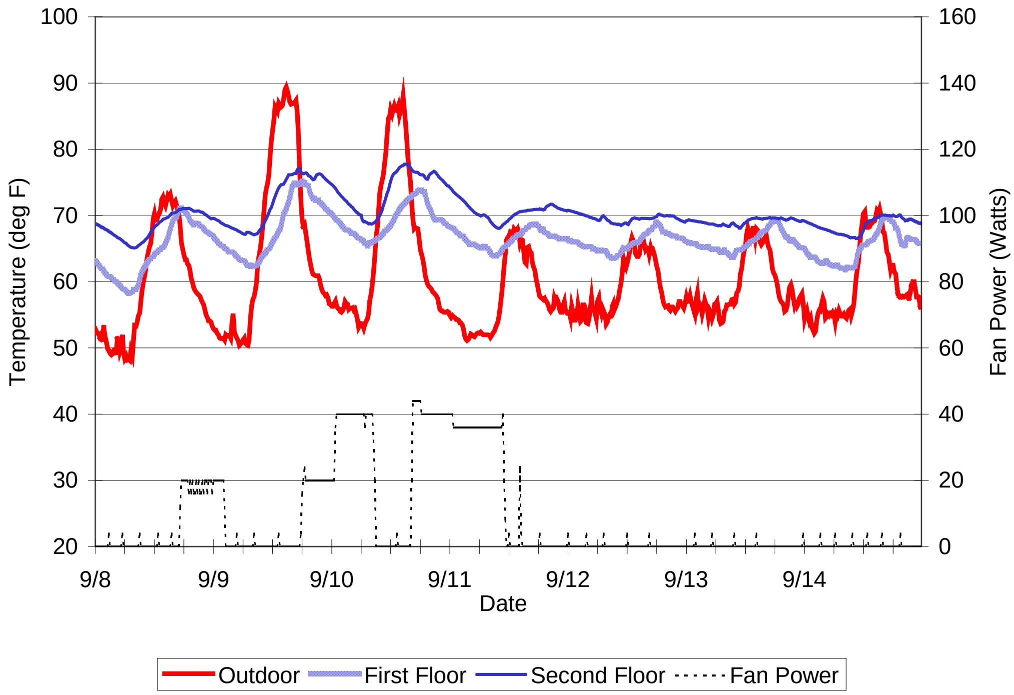

Figure 17. Indoor & Outdoor Temperatures and Fan Power, Watsonville Site, September 2002

Livermore Site Monitoring Summary. Monitoring was initiated at the Livermore site in July of 2002. As of this date monitoring is continuing in order to provide data for the Zero Energy Home project. No date for removal of the equipment has been established, and the owners are both receptive to continue monitoring and eager to obtain information about the performance of their home.

Because the house was not occupied during the summer of 2002, data collected for this period are of limited value, however, a full summer of data was collected for 2003. The most significant observations from these data are listed below:

- During the summer of 2003 there were 15 days with temperatures over 100°F, but the two air conditioners were operated for a total of only 8.9 hours during these months.
- The highest indoor temperature recorded was 82°F, and this occurred on the fifth day of a five-day heat storm with maximum outdoor temperatures averaging 103°F.
- The highest HVAC system demand recorded for the summer of 2003 was 4.2 kW, recorded in July when both air conditioners were operating concurrently. The highest demand recorded for May, June, August, and September was 2.3 kW.
- The "EER" of ventilation cooling averaged 54 Btu/Watt-hour, or roughly six times higher than the nominal efficiency of typical new air conditioners (i.e. an EER of 9).

Perhaps most significantly, ACC design improvements coupled with the 3.6 kW photovoltaic system installed enabled the house to produce 102% of total household electrical energy consumption for the period between August 2002 and July 2003. Electric bills from May 24 through October 15, 2003 averaged $4.55 per month (meter charge).

Figure 18 profiles indoor and outdoor temperatures recorded during a week in July of 2003. Fan and air conditioner power are plotted on the same graph. With maximum temperatures approaching or exceeding 100°F, the indoor temperature was kept generally below 80°F with one of the two air conditioners operating for a brief period on one day. Combined ventilation fan power for both NightBreeze systems was less than 500 Watts on most nights.

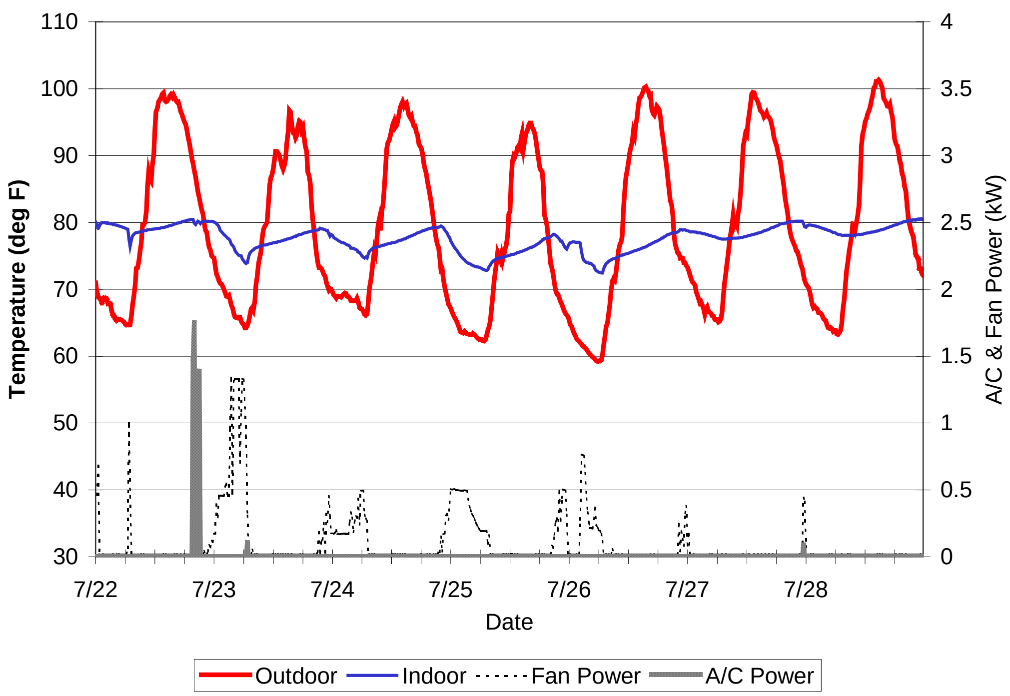

Figure 18. Indoor & Outdoor Temperatures and Cooling Power, Livermore Site, July 2003

As described in Section 2.2.3, in heating mode the NightBreeze fan delivers air at a rate that is proportional to the difference between the indoor temperature and the thermostat setting. As a result, winter fan energy use is significantly less than for furnaces, which typically draw between 300 and 700 Watts. Figure 19 plots a typical heating cycle for a December day. The thermostat setting is set back at 1 AM and raised at 9AM. The system responds to the increased setting by turning on the fan, which initially draws about 160 Watts. As the indoor temperature increases the fan ramps down, until it is only drawing about 25 Watts to maintain the thermostat setting. For this 24-hour period, fan power averaged 30 Watts. The circulating pump, which draws about 85 Watts and runs 16 hours per day, raises the average HVAC power demand to 87 Watts.

Since the pump is water lubricated, some of this energy is returned to the water in the form of heat.

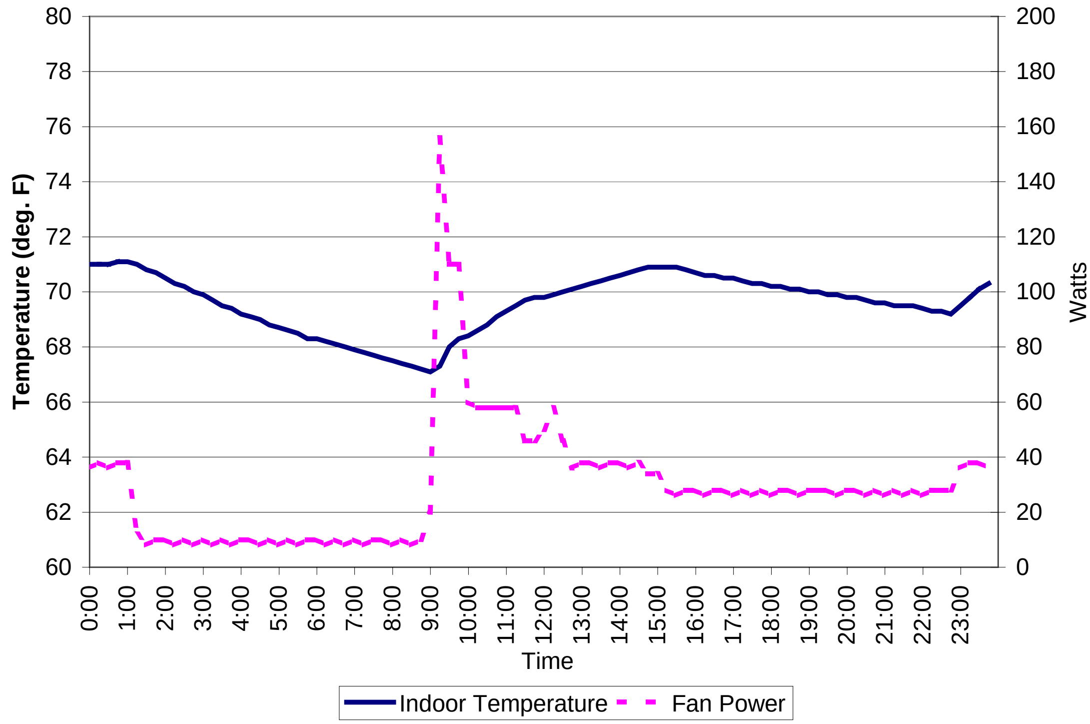

Figure 19. Typical Profile of Indoor Temperature and Fan Power in Heating Mode

Figure 20 plots a comparison of the performance of the ACC house (Lot 78) to the "control" house (Lot 55) on July 25, 2003, a reasonably typical summer day. The outdoor temperature dropped to a low of 63°F and rose to a high of 95°F. The indoor temperature of the control house was maintained between 77° and 78° with the air conditioner cycling on and off almost continuously, except for the early morning hours. The control house used about 21.7 kWh energy during this 24 hour period. By contrast, the indoor temperature of the ACC house ranged from a low of 73° at 7:30 AM to a high of 78° at 8:45 PM. The air conditioner did not operate at all, and the fan, which only ran during off-peak hours, used a total of 4.1 kWh. Thus the ACC design resulted in a 5-fold reduction of cooling energy use while keeping the house at a lower average temperature, which would presumably be considered more comfortable.

System Operation, Both Sites. The Watsonville NightBreeze system operated as designed. Monitoring data from the Livermore site showed the fan in one of the air handlers was operating at a higher speed than programmed by settings, and the same system had problems with excessive damper cycling. Upon replacement of the controller and wall display unit these problems were resolved. Since the firmware for the original and replacement controls was identical it is believed that control hardware was the source of this problem.

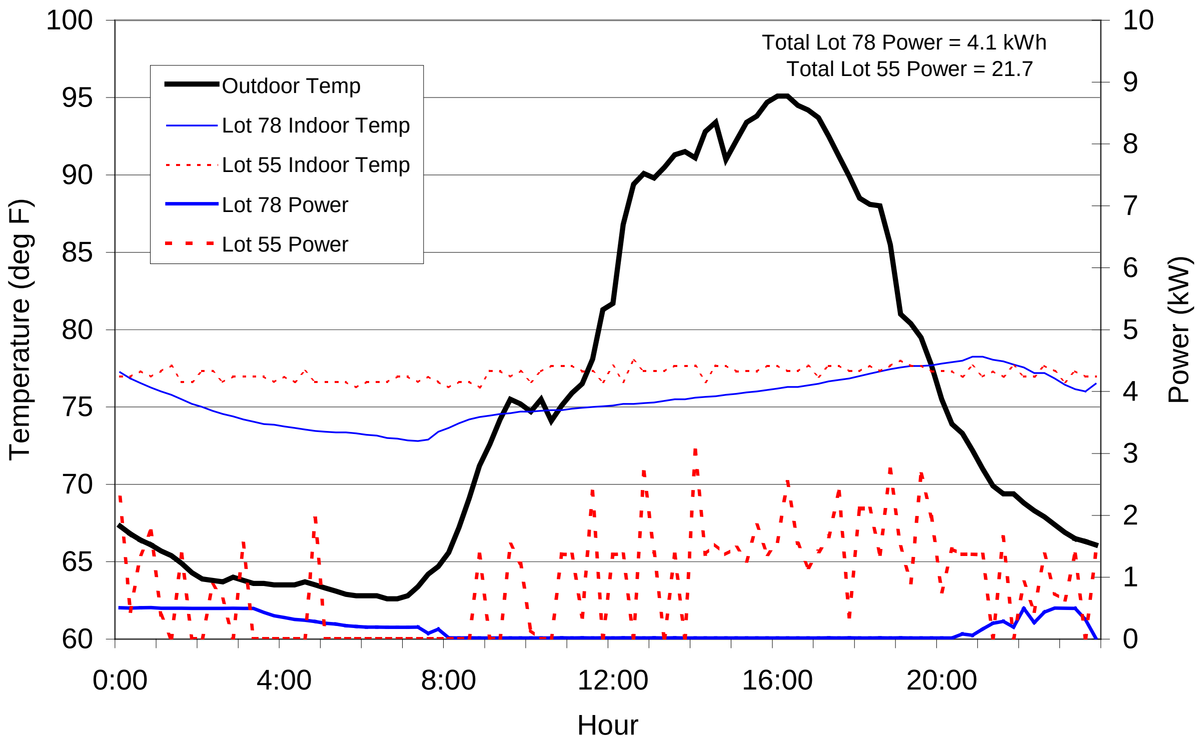

Figure 20. Typical Summer Day Comparison of Indoor Temperatures and Energy Use of the Control House (Lot 55) and the ACC House (Lot 78)

2.4.6 Computer Simulations Using the Calibrated Model

Model Calibration. Computer simulations have fixed schedules of internal heat gain and thermostat settings. Irregular occupancy, varying thermostat settings, use of windows and lighting, and other behaviorally influenced factors are impossible to model. Instead of ignoring these factors and forcing the simulation model to match the energy use of the demonstration homes, we employed another calibration approach that is more likely to produce reliable results.

Since air conditioning is activated by a thermostat that responds to indoor air temperature, the key question is whether the computer model can accurately simulate indoor temperature change, both as the house is ventilated and cooled, and as it heats up during the day. To accomplish calibrations, monitoring data were selected from days when no air conditioning was used, and indoor temperatures were separated into two outdoor temperature ranges: typical days (highs of 89°F to 100°F), and hot days (highs greater than 100°F). Indoor temperature changes for each hour of the day were calculated and averaged within these two bins. These data were then compared to similarly binned data from DOE-2 simulations. These calibrations were only completed for the Livermore demonstration house, since the owners of the Watsonville house rarely used the ventilation cooling system.

To achieve a best fit between monitored and simulated temperature data, it was necessary to add internal thermal mass to the model. Figure 21 graphs the results of this calibration, and shows that differences between simulated and monitored indoor temperature changes were generally less than 0.3°F.

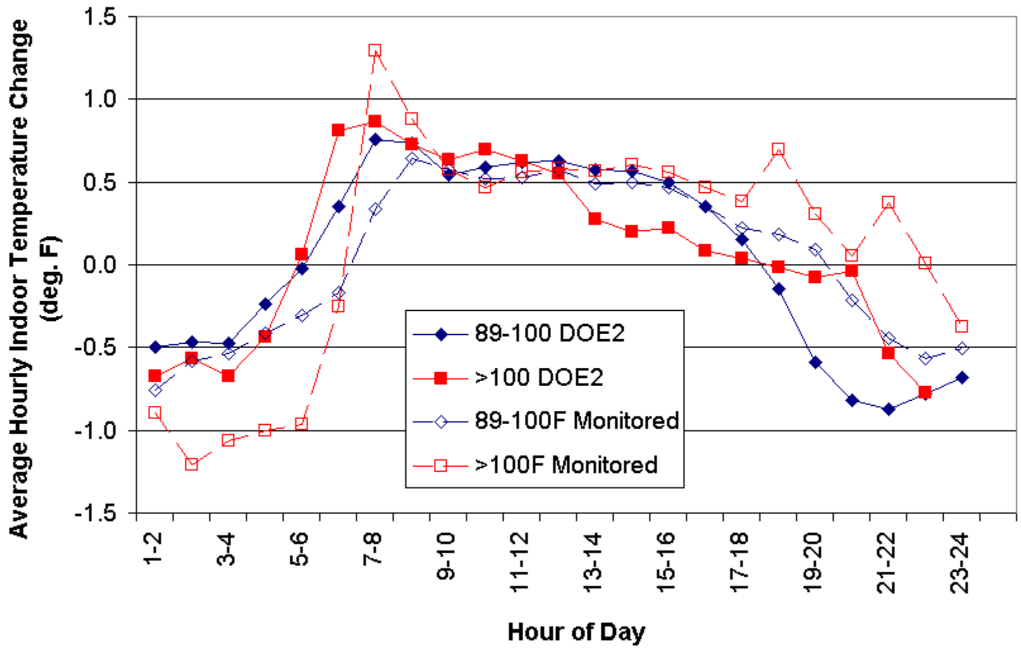

Figure 21. DOE-2 Simulation Model Calibration Results for Livermore House

A comparison of monitoring data to simulation data for the Livermore house shows the calibrated model predicted HVAC energy use to within 5% of actual usage. DOE-2 predicted usage of 857 kWh per year while monitored usage was 901 kWh between September 2002 and September 2003.

Performance Simulation in California Climate Zones. Using the calibrated model of the Livermore house, simulations were completed in all 16 California climate zones to estimate demand reduction potential and energy savings. To separate the effect of building envelope improvements from ventilation cooling, simulations were completed on a model of the Livermore house that met prescriptive Title 24 requirements, the same house with envelope and mass improvements, and the same house with ventilation cooling activated in the model. The Title 24 base case model was simulated without natural ventilation.

As shown in Figure 22, demand reduction percentage varies substantially by climate zone, ranging from 38 to 81%, with the highest percentage potential being in the more mild zones where ventilation cooling effectively eliminates cooling demand. Since the more mild zones have the least cooling energy demand, the warmer climate zones (11-15) actually offer the greatest kW demand potential. Climate Zone 1 requires no mechanical cooling, and so there is no demand reduction. The contribution that ventilation cooling plays in reducing peak load also varies by climate zone. In Climate Zones 3 and 5 building envelope improvements reduce the cooling load to the extent that ventilation cooling has little value other than to improve comfort. This result is consistent with our findings from the Watsonville house, which is in Climate Zone 3. These results show a slight improvement over the previous findings using the uncalibrated model with the Inland Valley House displayed in Figure 13.

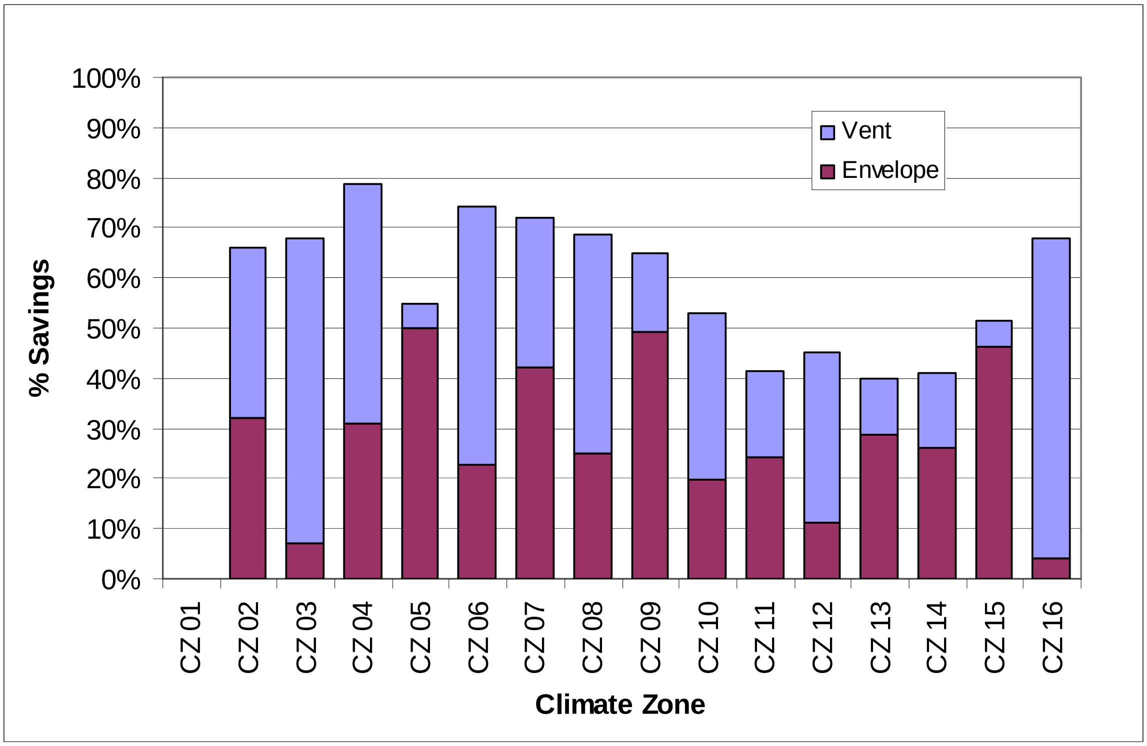

Figure 22. Simulated Demand Reduction from Calibrated Livermore House Model

A long-standing question that was the premise of the ACC project is whether air conditioning can be eliminated in California's "transition" climate zones. Monitoring data from the Watsonville house verified that air conditioning can be eliminated in Climate Zone 3. Figure 23 compares overall peak demand for the base case house designed to Title 24 standards vs. demand for the ACC design. Simulations show a demand of just below 1 kW (indicated by the solid line) for Climate Zone 3 for the ACC design. From these results it could be concluded that where the cooling demand is less than 1 kW, comfort can be reasonably well maintained without air conditioning by applying ACC designs. Other climate zones that fall below the 1 kW line in Figure 22 include 1, 4, 5, and 6. Zones 2, 7, 8 and 16 fall between 1 and 2 kW and with special attention to the building design compressor-based cooling may be avoided in those climate zones.

Figure 24 graphs simulated energy savings for the 16 climate zones using the calibrated Livermore model. Envelope improvements in Climate Zones 1, 3, 5, and 6 produce savings, but the small amount of air conditioner energy that is offset in these zones does not warrant mechanical ventilation cooling, although comfort would be improved by its use. There are no savings from envelope improvements in Zone 16 because lower window solar heat gain factors and the attic radiant barrier increase heating fan operation, hence ventilation is responsible for all energy savings in that climate zone.

Comparing these results to the results from the uncalibrated Inland Valley House model (Figure 11 & Figure 12), the calibrated model predicts slightly lower overall energy savings in the hotter climate zones and more significantly lower savings in the cooler zones, particularly Zone 6.

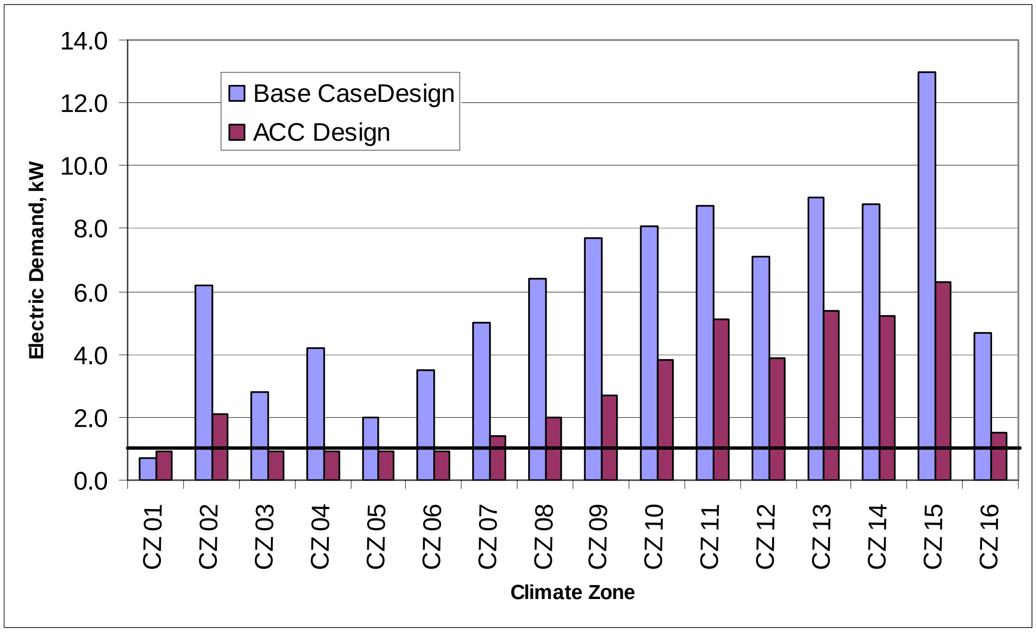

Figure 23. Simulated Cooling Demand for Base Case (Title 24) and ACC Designs

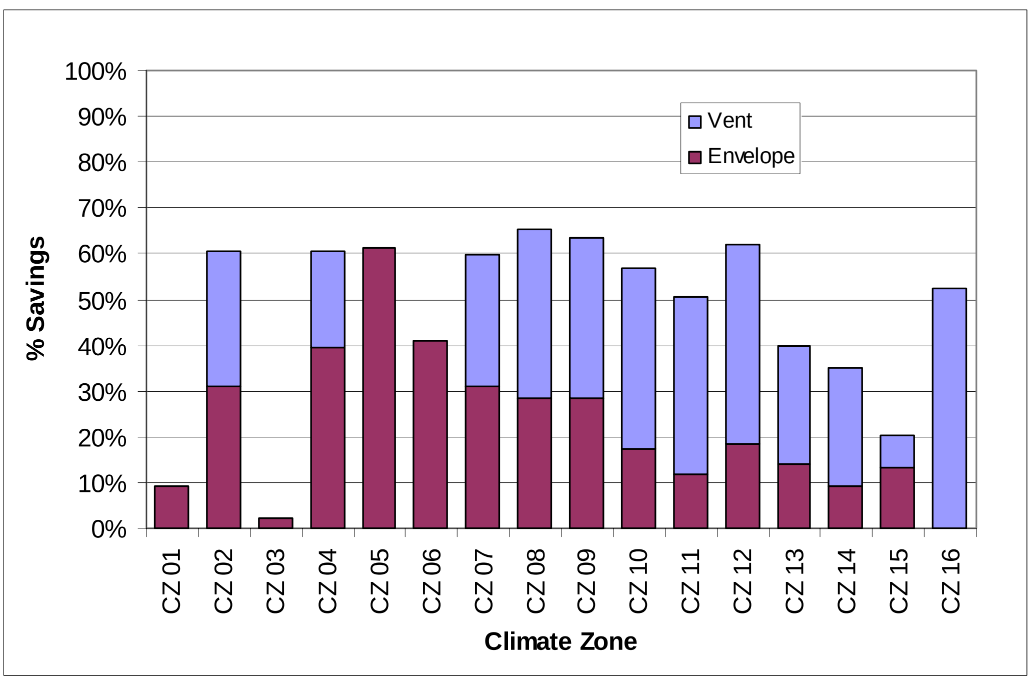

Figure 24. Simulated Cooling Energy Savings from Calibrated Livermore House Model

With rare exceptions ventilation cooling occurs exclusively during off-peak hours. If time-of-use rates are applied, electricity to cool the house by ventilation is purchased at a lower rate than electricity purchased to run the air conditioner. To measure this benefit, DOE-2 energy use was separated into on-peak and off-peak periods and current PG&E E-7 time-of-use rates were applied to both the base case and ACC models of the Livermore house. Figure 25 displays the predicted electric utility savings for all climate zones. Cost savings were calculated using PG&E time-of-use rates, listed in Appendix A. Even though there are no energy savings in the cooler climate zones, the favorable utility rates result in cost savings to the homeowner. The hotter climate zones offer the greatest cost savings.

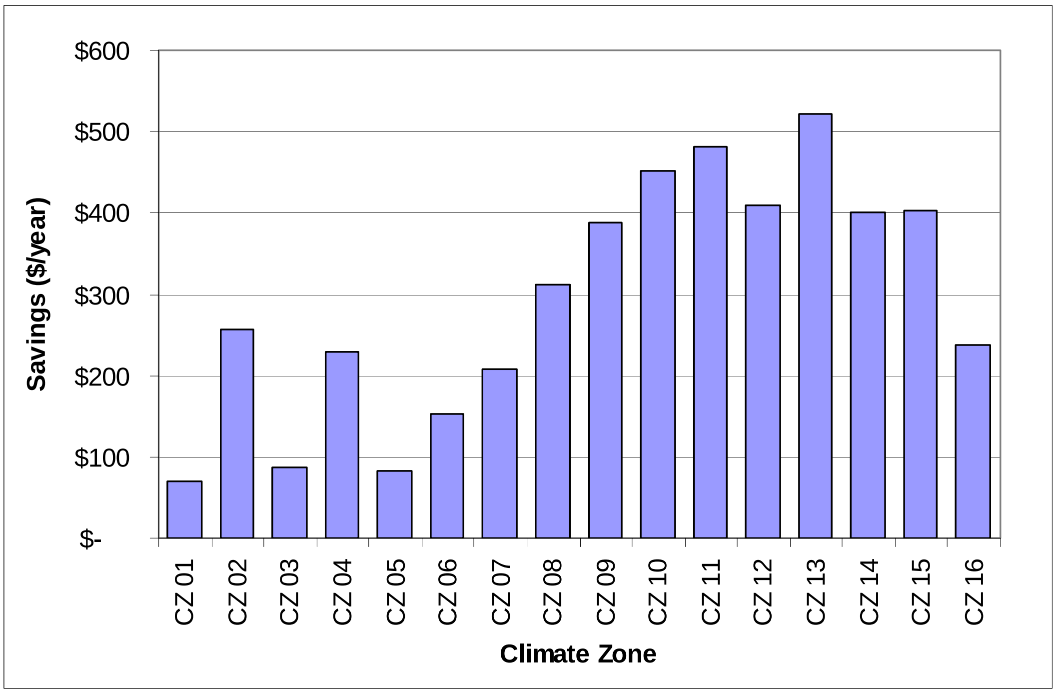

Figure 25. Simulated Utility Cost Savings from Calibrated Livermore House Model

Table 6 provides numerical results of the Livermore House simulations expressed in kWh and kW instead of percentages. Electrical usage includes fan energy for both heating and cooling, pump energy, and condensing unit energy. Incremental annual cost savings are listed for envelope improvements only, ventilation cooling, and for envelope plus ventilation cooling. Complete simulation results are tabulated in Appendix D.

Table 6. Summary of Annual Energy Savings and Undiversified Demand Reduction Results from Calibrated Livermore House Model

	Envelope Savings			Vent Cooling Savings			Total Savings			
Climate Zone	**HVAC kWh**	**Energy Cost***	**Demand kW**	**HVAC kWh**	**Energy Cost***	**Demand kW**	**HVAC kWh**	**Energy Cost***	**Energy Cost****	**Demand kW**
CZ 01	7	$1	0.0	No savings			No savings		$69	0.0
CZ 02	415	$69	2.0	400	$59	2.1	815	$128	$256	4.1
CZ 03	2	$0	0.2	No savings		1.7	No savings		$87	1.9
CZ 04	426	$69	1.3	226	$32	2.0	652	$101	$229	3.3
CZ 05	58	$8	1.0	No savings		0.1	No savings		$82	1.1
CZ 06	241	$35	0.8	No savings		1.8	235	$32	$153	2.6
CZ 07	286	$47	2.1	264	$39	1.5	550	$86	$208	3.6
CZ 08	505	$86	1.6	663	$108	2.8	1,168	$193	$312	4.4
CZ 09	661	$120	3.8	814	$138	1.2	1,475	$259	$389	5.0
CZ 10	547	$110	1.6	1250	$235	2.7	1,797	$345	$452	4.3
CZ 11	443	$98	2.1	1432	$280	1.5	1,875	$378	$480	3.6
CZ 12	474	$94	0.8	1134	$194	2.4	1,608	$288	$409	3.2
CZ 13	761	$171	2.6	1377	$284	1.0	2,138	$455	$522	3.6
CZ 14	413	$94	2.3	1182	$241	1.3	1,595	$335	$400	3.6
CZ 15	1,303	$305	6.0	699	$145	0.7	2,002	$451	$403	6.7
CZ 16	(12)	$2	0.2	650	$103	3.0	638	$105	$237	3.2

***Based on E-1 (flat) rates
****Based on E-7 (time-of-use) rates

2.4.7 Incremental Costs

Overall incremental costs for the addition of Summer Performance features to the homes were $7458 for Watsonville, and $17,500 for Livermore. Table 7 provides a breakdown of these costs. Costs for the Livermore site included a trellis that added $8900 and slab perimeter insulation that cost an additional $2500. Because they are clearly not cost effective, these two measures are not included in Table 7,[14] and they were excluded from the analysis reported in Section 2.4.6.

Incremental costs for ACC improvements are likely to be much lower in a production home scenario, and costs reported by Clarum Homes and Centex Homes could be substantially reduced by competitive bidding and inclusion of ACC measures as builder options or standard features. The last column of Table 7 provides estimates of production level costs for the measures. As suggested by computer analysis and experience with the Livermore demonstration, the air conditioner can be downsized by

[14] Subsequent studies completed for the Zero Energy Homes project showed the slab perimeter insulation and trellis contributed less energy savings than anticipated and are not cost effective.

at least one ton, so estimated costs conservatively take credit for a one-ton reduction at about $300 per ton.

Costs are also not included for converting carpeted floor coverings to tile or hardwood, since many homes already include nearly 50% hard surface floors on the first floor (for kitchen, entry, baths, dining), and tile and wood floor coverings are desirable upgrades for other reasons than energy efficiency.

The last line of Table 7 provides incremental annual mortgage costs corresponding to each incremental cost total. Mortgage terms are assumed to be 30 years at 6% interest. Comparing the incremental mortgage costs from Table 7 to the annual (TOU) energy savings from Table 6 shows that the ACC design options produce a positive annual cash flow in Climate Zone 13 using Watsonville costs, 10-15 using Livermore costs, and 8-16 plus 2 and 4 using estimated production costs. The ability to eliminate the cost of the air conditioner in Zones 3 through 6 (see Fig. 22) suggests that ACC designs may be cost-effective[15] in all California climate zones except 1 and 7.

Table 7. Actual and Estimated (Production Level) Costs for ACC Upgrades

Measure	Watsonville Costs	Livermore Costs	Estimated Costs
Radiant barrier roof sheathing	$520	$846	$500[16]
Upgrade windows from vinyl double pane to vinyl double pane Low-E^2	$401	$0	$0
Upgrade drywall from ½ " to 5/8"	$600	$400	$500
Upgrade water heater from gas storage to high efficiency-high capacity, plumbing connections to air handler	$4140	$2447	$1200
A/C downsizing credit	$0	$0	<$300>
Replace 80 AFUE furnaces with NightBreeze air handlers and install damper	$1797	$2220	$1500
Totals	$7458	$5288	$3400
Incremental annual Mortgage cost	$480.43	$380.91	$219.02

2.4.8 Owner Interviews

With assistance from researcher Bruce Hackett we developed a list of questions for the purpose of interviewing the owners of the two demonstration homes. The intent of the interviews was to determine how satisfied the owners were with the level of comfort provided, and to assess their understanding of the energy features, especially the NightBreeze systems. A more complete summary of the interviews is included in Attachment 3.

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[15] Cost-effectiveness here defined as annual energy savings that exceed incremental annual mortgage costs at 6% interest and a 30 year term.

[16] Although an attic radiant barrier is required under California Title 24 prescriptive standards, the baseline model did not require it in order to comply with the Title 24 performance standard.

We interviewed "Rita", the head of the household at the Watsonville house, on May 28th and June 23rd 2003. Rita works full time at a nearby health facility, and has one child. Her responses to questions indicated she understood the principals of ventilation cooling. Some of her responses suggested she had some misconceptions about the dynamics of heating and cooling systems. For example, when asked why she didn't use the heating system she said that when she turned it on it heated the house in a very short time, which caused her to be concerned that it would use a lot of energy and be expensive to operate. She and her family "tend to be cold people, which is why the house works well for them." However, she did find it a little too cold last winter because she didn't use the heating system. In summer she doesn't mind the house being cooler at night. She also said that if she were to buy another home she would like the same system.

"Tina" and "Tony", owners of the Livermore house were interviewed on April 9, 2003. They have no children. Tony is an airline pilot and Tina works mostly at home. Since they had moved in the previous October they had no experience of the house in summer weather. Tina commented that the house "feels like a cave", in that the temperature doesn't change very rapidly. They acknowledged that this characteristic would be more of a benefit in the summer. When outdoor temperatures were pleasant it felt too cool inside the house and they opened windows to warm it up. They were shocked by a $677 gas bill for the months of October through March, most of which was the result of running their gas fireplace nearly all day and in the evenings. Since they were not billed for gas usage for several months through the summer it was also apparent that PG&E discovered a billing error. Tina said she was not completely comfortable with the use of the thermostat, mentioning specifically the "Vacation" mode, which she has not seen on other thermostats. She finds it complicated, but said the thermostat in her previous home was also difficult to use. For winter, they said they programmed the thermostats to maintain 70°F between 5 PM and 11 PM.

We were in contact with Tina and Tony through the summer of 2003, and they were very pleased with the comfort of the house, their ability to avoid using their air conditioners, and their extremely low energy bills. Tina likes to keep the house warmer, and frequently shuts off the cooling system. Tony said he turns the ventilation cooling on when he gets home from his trips, since he likes it cooler.

3.0 Summary of Project Outcomes

3.1 NightBreeze Air Handler & Damper

3.1.1 Design

A "NightBreeze" air handler and damper combination was developed that fully meets requirements for integrating ventilation cooling with heating and air conditioning, including the capability to deliver from 500 to 2000 CFM for meeting cooling loads up to five tons. A damper that is currently manufactured by Beutler Corporation for ZTECH was found to be suitable for this application. A prototype air handler with variable speed ECM motor and dual function coil was designed and built for testing purposes. Subsequently, production prototype air handlers were built by EMI for use in demonstrations. Davis Energy Group is currently fabricating prototypes for deployment in demonstration projects. DEG is considering formal production pending completion of U.L. testing and certification.

3.1.2 Damper and Air Handler Testing

The outside air damper and prototype air handler were tested at PG&E's TES facility. The damper survived over 10,000 cycles without failure (equivalent to about 50 years of operation), and leakage tests showed an acceptable 1.4% of total airflow. Air handler tests showed that use of a dual function coil for hot water for heating and refrigerant cooling did not offer significant improvement over standard coil performance. Fan energy was measured at 0.20 Watts per CFM at 1000 CFM and 0.33 Watts per CFM at 1500 CFM. (DOE SEER ratings assume 0.365 Watts per CFM).

One attribute of the ECM fan motor is that it maintains a constant airflow over a wide range of static pressures. Tests were completed on pre-production air handlers built by EMI to verify that the motor was properly programmed by varying static pressure at discrete airflow settings ranging from about 500 to 2000 CFM. Tests determined that the maximum change in airflow when static pressure was varied from 0.1 and 0.6" static pressure was 10%. These tests also showed higher efficacy (CFM per Watt) than PG&E tests, probably as a result of reduced coil resistance; these units had two-row heating-only coils instead of dual function heating-refrigerant cooling coils used in the original prototype. See Attachment 1 for damper and air handler test results.

3.2 NightBreeze Controls and Documentation

3.2.1 Functional Specifications and Design

Controls were developed using prototype designs from the prior project phase, using functional specifications developed in the current phase. Integrated control functions include ventilation cooling, heating, air conditioning, and winter fresh air ventilation. A vendor was identified for the control hardware, and revisions to the hardware were made, including integration of a power supply and addition of specific outputs for controlling a pump and the ECM fan motor. User interface graphics were refined and firmware was developed for the wall display unit and controller. Firmware was debugged and tested, and is production-ready. See Attachment 4 for functional specifications.

3.2.2 Control Testing

Laboratory and field testing was completed and resulted in further refinements to the control firmware. Responses from reviews of a web-based virtual thermostat and in-home interviews were also used to identify improvements. See Attachment 3 for interview results.

3.2.3 Documentation

A brochure describing system features was developed to interest builders in participating in demonstrations, and to solicit market feedback. An owner's manual and installation manual were also developed for use by installers of demonstration systems, and by buyers of demonstration homes. See Attachment 2 for copies of the documentation.

3.3 Inland Climate Design Results

3.3.1 Inland Climate House Design

A complete house design oriented toward production builders was developed for demonstrating "Summer Performance Home" characteristics for construction in inland climate locations. The design included architectural and mechanical drawings and specifications, and was presented to builders potentially interested in constructing demonstration homes. Though builders opted not to use the specific design, it proved to be instructive of how ACC measures could be applied without impacting appearance.

3.3.2 Inland House Performance

The DOE-2.1E simulation program was modified to include a special function for emulating NightBreeze control functions. This model was used to simulate performance of the Inland Climate House in six representative climate zones. Results showed demand reduction ranging from 30 to 93% and energy savings ranging from 35 to 94%. See Attachment 6 for the full report.

3.3.3 Human Comfort Investigations

A survey of 50 homeowners was completed to determine attitudes toward comfort, management of thermostats and windows, ventilation cooling, and use of controls. An extensive bibliography of references on residential comfort was compiled and reviewed, and a report was completed on the subject of comfort criteria in residential buildings. These documents are provided in Attachment 3.

3.4 Field Test Construction & Monitoring

3.4.1 Field Demonstrations

Presentations to production builders resulted in commitments from Clarum Homes and Centex Homes to build Summer Performance demonstrations located in Watsonville (Climate Zone 3) and Livermore (Climate Zone 12) respectively. HVAC designs and specifications were completed for both homes and meetings were held with builders and subcontractors to review changes.

The Watsonville house was completed in September 2001 and the Livermore house in September 2002. One NightBreeze system was installed without air conditioning in Watsonville, and two NightBreeze systems were installed (as two zones) in Livermore. No significant problems have been encountered since the systems were commissioned. Other building features are listed in Section 2.4.2. Photos of the two houses are provided in Appendix C.

3.4.2 Construction Experience & Builder Feedback

Summer performance measures were installed without any major difficulties. The 5/8" drywall added for thermal mass required custom doorjambs because of the increased wall thickness; this could be avoided by only increasing drywall thickness at ceilings. The other approach to increasing mass, using hard surface floor coverings over concrete slabs, was appealing to buyers and acceptable to builders.

The installation of slab perimeter insulation at the Livermore house required special attention by the Centex construction superintendent. At a cost of $2750 and with a one day delay in the construction schedule this measure was not popular with the builder. Trellises installed at the Livermore house for exterior shading cost $8830, and though attractive are not considered a viable solution for production homes. Lower-cost architectural solutions such as extended overhangs and inset windows would also improve shading. The attic radiant barrier roof sheathing was the easiest to implement of all measures.

HVAC contractors had no difficulty installing NightBreeze systems, though plumbing contractors were not used to combined space heating/domestic water heating systems and one required careful supervision. The two-zone Livermore house required two NightBreeze systems, but a single two-zone system would have sufficed if it had been available, resulting in nearly a 50% reduction in installed cost.

Neither HVAC contractor has shown an interest in using NightBreeze on other projects, but Centex Homes has adopted a furnace-based version as a buyer option in a San Ramon development that will break ground in November, 2003.
High capacity, high efficiency water heaters were installed for both domestic water heating and to serve as a source of heat for the NightBreeze air handlers. At over $2000, the condensing water heater (used at Watsonville) is less attractive than the instantaneous water heater used at Livermore, which costs less than $1000 to the contractor.

Incremental costs for the addition of Summer Performance features to the homes were $7858 for Watsonville, and $17,500 for Livermore. Elimination of the trellis and slab perimeter insulation measures reduces the Livermore incremental cost to $5288 (see End Note #14). If applied as standard options, the Summer Performance package cost could be reduced to $3400, including credits for downsizing the air conditioner by one ton.

3.4.3 Monitoring Results and Operational Experience

More than one year of monitoring data was collected from each of the two houses. Total annual HVAC energy use, including air conditioner energy; system fan energy for ventilation, air conditioning, and heating; and pump energy was 93 kWh for the Watsonville house and 901 kWh for the Livermore house. The owners of the Watsonville house rarely ran their HVAC system in summer or winter, and tolerated indoor temperatures as low as 55°F in winter and as high as 83°F in summer. The owners of the Livermore house were content with temperatures of about 70°F in winter and 80°F in summer, and used their two air conditioners for a combined total of 8.9 hours during the summer of 2003. Table 8 lists total monthly fan and air conditioner energy use broken down by total and on-peak periods, as well as maximum demand for each month and hours of air conditioner operation. Only 14.7% of the energy use occurred during PG&E's 12 PM to 6 PM on-peak period. During the monitoring period the two-ton air conditioners at Livermore were observed to be operating concurrently on only one occasion, indicating that one two-ton unit could have provided the necessary cooling capacity for the 3080 ft^2 house, resulting in a sizing ratio of 1540 ft^2 per ton (or 0.65 tons per 1000 ft^2). Comparing this value to the mean sizing ratio of 543 ft^2 per ton (or 1.84 tons per 1000 ft^2) determined from an inspection of 30 California production homes (Hoeschele 2002) shows that the ACC design may have made possible more than a 50% reduction in air conditioner size. This size reduction potential was more than confirmed by comparative monitoring between the ACC house and a control, which showed a five-fold decrease in cooling energy use over a typical summer day. With the reduced cooling load, the 3.6 kW of photovoltaic modules installed on the Livermore house were able to produce more electricity than used by the house over one year.

Table 8. HVAC Energy Use and Air Conditioner Operation, Livermore 2003

Month	Total HVAC Energy (kWh)		Maximum Demand (kW)	Total Hours of A/C Operation
	Total	On-Peak		
May	51	9	1.14	0
June	50	7	2.28	0.9
July	70	12	4.17	7.5
Aug	38	4	1.74	0.4
Sept	36	4	1.47	0.1
Total	245	36		8.9

3.4.4 Development of Calibrated Simulation Model and Simulation Results

Section 2.4.6 describes the methods employed to calibrate the DOE-2 simulation model. A comparison of total annual HVAC electrical use determined using the model to monitored electrical energy use for the Livermore house showed they differed by only 5%.

Simulations were completed for all 16 California climate zones using the calibrated Livermore house model. Table 9 lists demand reduction and energy savings using the same housing start and house size assumptions as used to estimate savings by the proposal for this project phase (DEG 1998). The calibrated model predicted 11% greater demand reduction and 14% lower energy savings than estimated in our proposal. Given the larger houses built today and increased construction volume, statewide savings would be closer to those represented in Table 10, which includes more current data on housing starts and assumes an average house floor area of 2000 ft² instead of 1800 ft². Table 10 shows that annual non-coincident peak demand reduction is more likely to be about 266 MW, and annual energy savings should be about 98 GWh if current construction trends continue. Dividing the statewide demand reduction from Table 10 by the number of housing starts shows that demand savings would average about 2.4 kW per household.

The reader should note that demand reduction values reported in Table 9 and Table 10 are end use, or non-diversified, loads. Diversity factors would have to be applied in order to estimate system-wide load reduction impacts. But according to Brown (2003) the load factor for residential air conditioning is only 7%, suggesting that this diversity factor is probably high, meaning that most air conditioners are probably running concurrently during the most severe hot weather events.

Table 9. Estimate of California-wide Annual Demand Reduction and Energy Savings Based on 1996 Construction Data, 1800 ft² Average House Size

Climate Zone	1996 Housing Starts	Demand Reduction kW	Energy Savings kWh	Total Demand Reduction MW	Total Energy Savings GWh
1	406	0	0	0.0	0.0
2	2283	4.1	815	5.4	1.1
3	4319	1.9	0	4.8	0.0
4	5619	3.3	652	10.8	2.1
5	1714	1.1	0	1.1	0.0
6	2133	2.6	235	3.2	0.3
7	5816	3.6	550	12.1	1.9
8	6990	4.4	1168	17.8	4.7
9	4500	5.0	1475	13.1	3.8
10	10226	4.3	1797	25.5	10.7
11	5030	3.6	1875	10.5	5.5
12	12630	3.2	1608	23.4	11.8
13	7905	3.6	2138	16.5	9.8
14	23	3.6	1595	0.0	0.0
15	2301	6.7	2002	8.9	2.7
16	444	3.2	638	0.8	0.2
Totals	72339			154.1	54.5
Estimates from proposal				138.6	63.3

Notes: To be consistent with the proposal, totals were factored by 0.58 to account for floor area differences between the 3080 ft² Livermore house and an 1800 ft² house.

Housing starts in the table were taken from 1996 CIRB data.

Table 10. Estimate of California-wide Annual Demand Reduction and Energy Savings Based on 2002 Construction Data, 2000 ft² Average House Size

Climate Zone	2002 Housing Starts	Demand Reduction kW	Energy Savings kWh	Total Demand Reduction mW	Total Energy Savings GWh
1	422	0	0	0.0	0.0
2	3364	4.1	815	9.0	1.8
3	3909	1.9	0	4.8	0.0
4	3200	3.3	652	6.9	1.4
5	1496	1.1	0	1.1	0.0
6	6932	2.6	235	11.7	1.1
7	6048	3.6	550	14.2	2.2
8	4141	4.4	1168	11.8	3.1
9	4622	5.0	1475	15.0	4.4
10	15172	4.3	1797	42.4	17.7
11	6618	3.6	1875	15.5	8.1
12	24671	3.2	1608	51.3	25.8
13	9497	3.6	2138	22.2	13.2
14	5510	3.6	1595	12.9	5.7
15	8810	6.7	2002	38.4	11.5
16	4055	3.2	638	8.4	1.7
Totals	108467			265.6	97.6

Notes: Totals were factored by 0.65 to adjust for floor area differences.
Housing starts in the table were taken from 2002 CIRB data.
Starts for the first seven months of 2003 totaled 114,374.

3.4.5 Owner Reactions

Both owners are content with their homes and would consider buying another home with the same features. Owners of the Livermore home are particularly enthusiastic about their low utility bills and lack of need for air conditioning.

3.4.6 Other Outcomes

Centex Homes, builder of the Livermore demonstration house, is planning to build two more model homes in the Windemere development in San Ramon under the DOE/NREL Zero Energy Homes program. These homes will include an early release of the furnace-based NightBreeze system. The NightBreeze system and other zero energy features will be marketed to buyers under Centex's "PowerSave" label and will be marketed through in Centex's new design studio, also located in San Ramon.

4.0 Commercialization (Where Do We Go from Here?)

4.1 Production Opportunities

During the course of this project we have continually sought the participation of a manufacturer. In October of 2000 Davis Energy Group entered an agreement with ECR International, parent company of Enviromaster International (EMI), licensing EMI to produce and market NightBreeze systems. DEG and EMI worked together to develop and test a production model. Just prior to the expected release date in August 2002 EMI decided to withdraw from the agreement. The primary reason cited was concern over their inability to adequately market the product due to its high cost.

Subsequent efforts to find interested manufacturers have not produced results. As of August 2003 DEG has itself produced fourteen units that are committed to various projects. Four have been installed in custom homes, eight are going to a Southern California Edison supported Habitat for Humanity project, and one to a Building America supported project. Pending receipt of a U.L. listing, DEG may launch small-scale production out of its own facilities until the product can be handed off to another manufacturer.

4.2 Product Enhancements

4.2.1 "Phase Last" Project

Despite favorable experience with the hydronic-based NightBreeze ventilation cooling system used in the demonstration homes, builders are reluctant to introduce it as a buyer option because they are concerned about buyer acceptance, subcontractor capabilities to install combined systems, but primarily because it is not formally in production.

The single zone capability of NightBreeze is also a severe market impediment since most two-story homes are now being equipped with two zone systems. However, builders are receptive to similar systems that utilize gas furnaces instead of air handlers, which use water-to-air heat exchange-based air handlers and require a hot water source. This tendency has been proven by Beutler Corporation, who installs SmartVent® systems in more than 5% of their projects.

In recognition of these market limitations, the California Energy Commission provided continuation funding which will enable development of a NightBreeze ventilation cooling system based around a variable speed gas furnace that will operate at least two zones. This project, NightBreeze Product Development, is currently underway and we plan to introduce systems with partial NightBreeze functionality as early as spring, 2004.[17]

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[17] NightBreeze Product Development, see at http://www.energy.ca.gov/pier/buildings/projects/500-02-026.html

4.2.2 Humid Climate NightBreeze

Another market limitation for NightBreeze is that ventilation cooling is not effective in humid climates. In humid climates outdoor air may be cooler than indoor air, but it has a higher enthalpy and higher relative humidity. In response to a DOE-SBIR solicitation DEG applied for and received funding to make use of the variable-speed capability of the NightBreeze air handler and its control versatility to develop a system that provides dehumidification by varying the air velocity through the cooling coil. At low air velocities cooling coils produce more latent and less sensible cooling. This approach offers a more efficient alternative to conventional dehumidifiers that heat air while dehumidifying it, thereby adding to the sensible cooling load. The ventilation cooling and fresh air ventilation functions would be retained, but controlled by enthalpy instead of dry bulb temperature. If successful, this project will expand NightBreeze markets into all climate areas of the state and nation.

4.3 Market Opportunities

4.3.1 State Program Opportunities for Marketing the "Summer Comfort" Package

NightBreeze systems installed in homes designed to meet Title 24 standards may be justified on the basis of energy savings and will reduce peak load. However, to achieve the maximum demand reduction potential, NightBreeze should be marketed as part of a "Summer Comfort" package of measures that include added thermal mass, attic radiant barrier, high performance windows, and enhanced exterior window shading. This integrated, or passive/active approach offers the greatest opportunity for eliminating air conditioning in transition climate zones, and substantially reducing capacity in inland valleys. The package approach can best be accomplished by developing a Summer Performance Home program, either as a CPUC supported effort or through Building America or other programs. Davis Energy Group submitted a proposal for CPUC funding in 2002, but it was not successful.

Currently the only California program that supports ventilation cooling is a PG&E rebate program for whole house fans and other ventilation cooling systems, but this program applies to existing construction only.[18] The Emerging Technology Coordinating Council could serve as a catalyst for initiating other utility programs.[19]

4.3.2 Federally-Supported Programs

Two federal programs, Building America and Zero Energy Homes also offer market opportunities. Building America's Consortium for Advanced Residential Buildings' (CARB) research plan currently includes support for NightBreeze development and demonstration efforts, and interest has been shown by one builder to demonstrate NightBreeze in a Building America-sponsored project.[20] Centex Homes is including furnace-based NightBreeze systems in two model homes to be built under the Zero

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[18] See http://www.pge.com/res/rebates

[19] See http://www.ca-etcc.com/

[20] See http://www.carb-swa.com/PDF%20files/CNJanuary04.pdf

Energy Homes program in the "Windemere" development in San Ramon. Centex is also offering NightBreeze as a buyer option with their "*PowerSave Plus*" package.

The Department of Energy, under the Small Business Innovation Research (SBIR) program, has also invested in research to expand NightBreeze capabilities to provide efficient humidity control in moist climates. Section 4.2.2 of this report describes this project in greater detail.

4.3.3 Non-supported Market Opportunities

A number of custom home owner-builders and contractors who learned about NightBreeze from the web sites and other sources have expressed interest. Also, a leading California supplier of hydronic heating components has expressed interest in listing it in their catalog. As of this writing there has been no advertising, and interest could be sparked by new product press releases to trade publications, and other advertising. Plans to publicly introduce the hydronic version of NightBreeze are being deferred until a U.L. listing has been obtained.

The basic furnace-based version will not require U.L. approval and is likely to be introduced in the spring of 2004. The variable speed multi-zone version will require approval by furnace manufacturers and may also require a U.L. listing, so its release will probably be delayed until late 2004 or 2005. Furnace-based NightBreeze systems can be immediately marketed through Beutler Corporation, who is a partner with DEG on the "Phase Last" PIER project.

4.3.4 Green Building Programs

NightBreeze fills the need for efficient cooling and heating, and improved indoor air quality, both of which are included in most green building guidelines and standards. Introduction of a residential LEED rating by the U.S. Green Building Council is likely to improve market opportunities. Personnel involved in Alameda County's Green Building Program have already promoted NightBreeze with other builders in their jurisdiction (see Section 2.4.1 end note).

4.3.5 Cost-Related Market Issues

The incremental cost to the contractor for a NightBreeze mechanical system[21] is about $1500, less if the air conditioner is downsized, and possibly zero if the air conditioner can be eliminated. This cost is approximately the same whether the standard furnace is replaced by a NightBreeze air handler and damper, or by a variable-speed gas furnace and the damper. The cost increment can be justified two ways, by showing that the added mortgage cost is less than the energy savings, and by pointing out the comfort and health benefits.

4.3.6 Business Plan Essentials

Concurrent efforts are underway to promote both hydronic and furnace-based NightBreeze technology. Although the hydronic version is essentially market-ready,

[21] This cost excludes added thermal mass and other measures that contribute to load reduction.

our plan is to keep production very low until we have gained experience from current demonstration programs and are assured that most of the potential implementation problems have been identified and resolved. Thenceforth, we may increase production capacity and institute an advertising campaign. Efforts will continue to license a manufacturing and marketing entity, and failing that, we will form a startup to perform this function.

The furnace-based version of NightBreeze will be manufactured and marketed by RCS/ZTECH, who currently builds and markets the SmartVent® system.[22] Initially, sales to Beutler Corporation will represent the greatest market, but we plan to help RCS/ZTECH expand the market statewide and nationwide as the advanced furnace-based product becomes available. Agreements that form the backbone of this plan are already in place.

4.4 Technology Transfer, Publicity, and Related Activity

4.4.1 Papers, Articles, and News Stories

A large body of published and unpublished reports have been compiled since the inception of the Alternatives to Compressor Cooling project, including several papers presented to ACEEE and a poster session on NightBreeze presented in August 2002. At least one more ACEEE paper is planned for the 2004 Summer Study. A list of all related publications is provided in References. During the course of the current project an article was prepared for and published in the July/August 2003 issue of *Home Energy* magazine, and an article on the Livermore demonstration house was published in the April 2003 issue of *Discover* magazine. Other articles on the Livermore home were included in the November/December 2002 issue of *California Builder*, the October 2002 issue of *Design/Build Business*, and the August 2002 issue of *R&D*.

The Livermore open house received publicity from local papers, including the July 11, 2002 issue of Contra Costa Times, and was the featured story on San Francisco Channels 5 (CBS, KPIX Eyewitness News at 4:30) and 7 (ABC, KGO News at 6) on July 10, 2003. A brief segment on NightBreeze was also filmed at David Springer's house and shown on ABC News Tonight with Peter Jennings on July 3, 2001.

4.4.2 Web Information

The California Energy Commission maintains web pages with information on all PIER projects. The Energy Commission also sponsored the filming of a video on the NightBreeze system, which is accessible through their Web site.[23] Davis Energy Group's Web site[24] devotes a page each to the ACC project and to NightBreeze technology.

[22] http://www.resconsys.com

[23] http://www.energy.ca.gov/pier/buildings/projects/500-98-024-0.html

[24] http://www.davisenergy.com

PDF file downloads of the brochure, installation manual, and operating manual, and a document describing the background of the project. Monitoring data for the Livermore house is also on display at the Florida Solar Energy Center Web site.[25] Loisos + Ubbelohde also maintains web information on the project with an emphasis on the architectural elements.[26] Information from previous project phases is provided at the California Institute for Energy Efficiency Web site.[27]

4.4.3 The AEC/ORNL PIER Study

Architectural Energy Corporation (AEC) has managed a PIER program titled "Energy Efficient and Affordable Small Commercial and Residential Buildings Research Program" that included a project titled "Residential Radiant Cooling And Heating Assessment". This study, conducted on the Winters, California home of David Springer, evaluated the performance of conventional air conditioning, and conventional air conditioning augmented by radiant floor cooling and night ventilation cooling via the NightBreeze system. Richard Murphy and Evelyn Baskin of Oak Ridge National Laboratory were principal investigators. Preliminary results, which showed significant peak load reduction by combining floor cooling and night ventilation cooling, were presented at a Radiant Panel Association conference in May, 2003, and the full study will be described in a PIER report scheduled for release by the Energy Commission in November. An ASHRAE paper is also planned.

4.4.4 Model Home Openings

Press releases were issued for both the Watsonville and Livermore model/demonstration home openings. The media were present for both openings, and articles appeared in local papers. The Livermore opening was attended by city and county dignitaries, and Dr. Woodrow Clark of the governor's office was one of the speakers. As a result of extreme high temperatures on the day of the opening the house was the feature story on both San Francisco television stations 5 and 7 that day.

4.4.5 Title 24 Efforts

Working under a contract to Heschong-Mahone Group and PG&E, Davis Energy Group led an effort to incorporate ventilation cooling into the California Energy Commission's 2005 California Residential Energy Standards (Title 24). The current Title 24 standard des not assign value to ventilation cooling. Research on this topic revealed that simulation models used for compliance (ACM's) over-value natural ventilation, thereby diminishing the impact of mechanical ventilation (Springer 2003). The ACM's also were shown to incorrectly model indoor temperatures, probably as a result of improper thermal mass assumptions. The code change proposal that was submitted to the Energy Commission's Building Standards program was denied on the basis that more information was needed on how people manage windows, and that any changes enacted on ACM assumptions would affect nearly all other measures, upsetting the balance that has been established. In light of the fact that for the first time the standards

[25] http://www.fsec.ucf.edu/bldg/active/zeh/livermore/index.htm

[26] http://www.coolshadow.com/Research/RProj_CoolAlter.html

[27] http://ciee.ucop.edu/Loisos1998/

will include time dependent valuation of energy, this is a particularly unfortunate decision.

5.0 Conclusions and Recommendations

5.1 Conclusions

5.1.1 Demand Reduction and Energy Savings Goals

The predominant goal of this project phase was to develop a marketable HVAC product that would have the potential to significantly reduce residential peak load. Calibrated model simulation results predict demand reduction 11% higher than estimated in our proposal, and energy savings 14% lower than originally predicted.[28] As indicated by Table 10, the annual non-diversified demand reduction should be about 266 MW, and energy savings about 98 GWh based on 100% implementation and one year's construction.

A long-standing goal of the ACC project has been to determine whether compressor air conditioning can be eliminated in transition climates. Elimination of the need to provide air conditioning was demonstrated by monitoring in Climate Zone 3. Simulation results indicate that compressor cooling can also be eliminated in zones 1, 4, 5, and 6, and possibly in zones 2, 8, and 16 (see Figure 22).

Both monitoring and simulation results point to a reduction in air conditioner sizing from the current mean of about 500 ft^2 per ton to over 1000 ft^2 per ton in inland valley locations. Reducing air conditioner size by 50% guarantees a 50% reduction in peak load. Eliminating air conditioning, which is feasible in transition climates, guarantees a 100% reduction.

5.1.2 Attainment of Other Proposed Goals

All goals stated in the proposal were met:

Goal 1 – Air Handler Development. Prototype and pre-production air handlers were developed and successfully field-tested.

Goal 2 – Improvements to Advanced Control. A market-ready version of the control was developed and successfully field-tested.

Goal 3 – Extension of Integrated House Design Applicability to Inland Climates. An inland climate house design was completed and analyzed.

Goal 4 – Commissioning, Evaluation, and Documentation of Demonstration Houses in Transition Climates. A demonstration house built in Climate Zone 3 confirmed that no air conditioning is needed in that climate zone, and that ventilation cooling enhances comfort. A second house was built in Climate Zone 12 and monitored. Performance exceeded expectations, with the air conditioners used for a combined total of 8.9 hours

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[28] These values are based on 1996 housing starts. Based on year 2000 housing starts, demand reduction would be 92% greater, and energy savings 54% greater, than the amounts originally proposed.

during the summer of 2003, and up to a five-fold decrease in cooling energy use on typical summer days. Except for a brief 4.2 kW demand in July, maximum HVAC system demand was less than 2.5 kW from May through September.

5.1.3 Other Lessons Learned

Besides validating our belief in the potential of the ACC design to reduce energy use, the most valuable lesson from this project was an understanding of how the production home industry operates and is motivated.

California production builders appear to be not quite ready for hydronic-based systems, but custom homebuilders are receptive, particularly those who have used radiant heating. Program efforts to stimulate replacement of storage gas water heaters with higher efficiency tankless gas heaters that serve as a source of space heating, and to encourage ventilation cooling would improve the market potential in the production home sector.

Furnace-based ventilation cooling systems offer a good intermediate alternative that the production home market will accept. Since a large amount of the energy savings measured and computed stems from reduced heating season fan energy, furnaces do not have the same energy savings potential as hydronic systems. Two-speed furnaces with ECM's can probably recapture a large part of these savings.

More tightly constructed homes built today can create indoor air quality and mold problems that have negative health consequences. While this project was underway, ASHRAE Standard 62.2 was adopted, which eventually may result in requirements for mechanical ventilation in many locations. By providing filtered fresh air, NightBreeze addresses the need for better ventilation, and provides it without consuming excessive fan energy, as other systems currently available are prone to do.

Time-of-use rates currently give ventilation cooling an advantage over compressor cooling. Mandatory time-of-use pricing or real time pricing would also greatly stimulate the market by making builders and buyers more aware of the importance of peak load reducing technologies.

Long-term programs such as Zero Energy Homes and Building America that help builders sell energy upgrades probably have a stronger chance for success and persistence than short-lived incentive programs such as PG&E's *Comfort Home*. Builders are most influenced by home features that allow them to differentiate themselves from other builders, earn them publicity, and particularly those that help them obtain entitlements from cities and counties for new development. This could be accomplished by educating local governments about available efficiency measures, as we were able to educate Alameda County through this project.

The emphasis to buyers and buyers should be on quality, comfort, and health. Also, buyers need to be shown that cost impacts are negligible or nonexistent. Builders, using trained sales staff, can educate buyers through the process of selling energy upgrades, and can profit from this activity just as they profit by selling granite countertops and other non-energy upgrades.

5.2 Commercialization Potential

The potential for commercialization has been addressed in other sections of this report, and is summarized below:

- The short-term commercialization potential for the hydronic-based NightBreeze system developed under this project is high for custom homebuilders and production builders participating in demonstrations.
- An immediate market exists for furnace-based systems in production homes.
- The long-term market potential for the hydronic-based system is high in all sectors if supported by market transformation programs that entice builders to apply the technology.
- It is easier to sell hardware than designs – this is why vapor-compression A/C units have become a standard residential technology – and a factor in managing California's peak electrical load problems. In contrast, the ACC "Summer Comfort" package integrates reasonable and commercially available architectural design measures with simple mechanical technology for 'free' ventilation cooling that allows adding vapor-compression A/C assist, if needed, operated under a single control system. This comprehensive approach will not be adopted by production builders unless it is actively promoted and integrated into their sales programs. Success of market-ready, energy-efficient technologies like this that can help shift peak load and reduce energy use in the state is therefore dependent on coordinated programmatic support. The success of such a program is suggested by the map provided in Appendix E.

5.3 Recommendations

Thanks to continued PIER support the market obstacle presented by resistance to hydronic heating is being removed. Beyond that, there are no economic or technological constraints on the commercialization of NightBreeze and the ACC package of measures. With time, and as a result of demand for reduced load and better indoor air quality, NightBreeze or similar systems will probably be found in all new homes. The following actions are recommended to ensure timely application of the results of this research:

A statewide CPUC-supported market transformation program: The state should move to insure that every new home is designed to reduce peak load (using ACC design principles) and mechanical ventilation cooling should be encouraged in most climate zones. Currently there is only one retrofit program for ventilation cooling (whole house fans) in the state. There are no statewide programs to encourage builders to construct homes to reduce peak load or air conditioner size.

Better collaboration between state and federal energy efficiency programs: There is interest in supporting ventilation cooling by both the Building America and Zero Energy Homes programs. Collaboration between these programs and state programs would boost the potential for rapid deployment.

Utility rate incentives: Actions should be taken by the CPUC, Energy Commission, and Power Authority to modify rate structures to reflect the true time value of electricity.

Recognition of ventilation cooling by state energy standards:. Proposed Title 24 standards changes that include time-dependent valuation of energy may induce builders to pay more attention to load-reducing strategies, but will not give credit to ventilation cooling. The Energy Commission should give strong consideration to including the ventilation cooling code change proposal submitted through PG&E for the 2005 standards into future rulemakings. This initiative should include modifications to alternative calculation methods to improve their accuracy in simulating indoor air temperatures. Perhaps the greatest value of implementing a Title 24 option would be that HERS raters would inspect systems to insure they are correctly installed.

5.4 Benefits to California

California and Californians will benefit from commercialization of NightBreeze and other ACC energy measures in the following ways:

- Reduced electric demand resulting in avoidance of the need for new powerplants, and less reliance on inefficient peaking plants, improving the bottom lines for utilities;
- Lower homeowner utility bills resulting in more discretionary spending, and thereby boosting the state economy;
- Lasting additions to the state's inventory of homes that will produce persistent energy savings and reduce powerplant emissions to improve air quality and reduce global warming;
- Improved indoor air quality, comfort, and home security;[29]
- Reduced stress on state electric transmission and distribution (T&D) systems and improved system reliability;
- Improved efficiency of water heating systems[30] without the need for tighter federal standards, which also reduces emissions and improves air quality;
- Increased sales volume for manufactures and suppliers resulting in increased tax revenue and more jobs.

[29] NightBreeze enables homes to be ventilated without the need to open windows.

[30] New federal standards will allow 50 gallon gas water heaters to have an energy factor of 0.58. Tankless water heaters used with NightBreeze hydronic systems have energy factors exceeding 0.80.

6.0 Glossary

ACC	Alternatives to Compressor Cooling
A/C	Air Conditioning, Air Conditioner
ACEEE	American Council for an Energy-Efficient Economy
ACM	Alternatives Calculation Method
ACS	Adaptive comfort standard
AEC	Architectural Energy Corporation
AFUE	Annual Fuel Utilization Efficiency
AMCA	Air Movement and Control Association International
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
Btuh	British thermal units per hour
CARB	California Air Resources Board
CFM	Cubic feet per minute
CIEE	California Institute for Energy Efficiency
CIRB	Construction Industry Research Board
CPUC	California Public Utilities Commission
DEG	Davis Energy Group
DOE	U.S. Department of Energy
ECM	Electronically Commutated Motor
EER	Energy Efficiency Ratio
EMI	Enviromaster International
Energy Commission	California Energy Commission
EPA	Environmental Protection Agency
FSEC	Florida Solar Energy Center
FTP	File Transfer Protocal
GWh	Gigawatt hour (1000 million Watt-hours)
HERS	Home Energy Rating System
HVCA	Heating Ventilation and Air Conditioning
LBL	Lawrence Berkeley Laboratory
LBNL	Lawrence Berkeley National Laboratory
LCD	Liquid Crystal Display
LEED	Leadership in Energy and Environmental Design (U.S. Green Building Council)
MINITAB	Statistical software package
MRT	Mean radiant temperature
MW	Megawatt (1 million Watts)
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
Pa	Pascals, a measure of pressure
PG&E	Pacific Gas & Electric Company
PIER	Public Interest Energy Research
PWM	Pulse width modulation
RCS	Residential Control Systems
RPM	Revolutions per minute
SBIR	Small Business Innovation Research (DOE program)
SCE	Southern California Edison
SEER	Seasonal Energy Efficiency Ratio

SMUD	Sacramento Municipal Utility District
TES	Testing and Environmental Services (PG&E)
Title 24	California administrative code governing building energy efficiency standards
TOU	Time-of-Use
UER	Universitywide Energy Research
WDU	Wall display unit

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8.0 List of Attachments

This section lists the attachments to the final report of PIER Project Alternatives to Compressor Cooling, Contract Number 500-98-024, conducted by Lawrence Berkeley National Laboratory. These attachments are part of report P500-04-009. To obtain copies of these attachments, or for more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200.

Report Title	**Publication #**
NightBreeze Product and Test Information • *NightBreeze Owner's Manual* • *NightBreeze Installation Instructions* • *Advanced Control Functional Specification* • *Advanced Control Functional Enhancements Report* • *Integrated Heating, Ventilation and Cooling Unit Test Report* • *Damper Test Report*	P500-04-009-A1
Summer Performance House Designs and Analysis • *Summer Performance Houses for California Climate Builder Information* • *Inland Climate House Performance Analysis Report*	P500-04-009-A2
Demonstration Project Reports • *Construction Process and Cost Evaluations* • *Occupant Response and Behavior* • *Monitoring Plan* • *Monitoring Reports*	P500-04-009-A3
Comfort Reports • *Advanced Comfort Criteria* • *Human Comfort Field Studies*	P500-04-009-A4

Appendix A: PG&E Rate Information

APPENDIX A
PG&E Rates Used in Analysis

Rate Tier	% of Baseline Use	E-1 Rate	E-7 Rate - Winter		E-7 Rate - Summer	
			On-Peak	Off-Peak	On-Peak	Off-Peak
1	100%	0.12589	0.10904	0.08119	0.30792	0.07783
2	130%	0.14321	0.12636	0.09851	0.32524	0.09515
3	200%	0.17713	0.16028	0.13243	0.35916	0.12907
4	300%	0.22106	0.20421	0.17636	0.40309	0.17300
5	>300%	0.24094	0.22409	0.19624	0.42297	0.19288

NOTES:

1. Baseline quantities are for PG&E Region S, and are 386 kWh in winter and 485 kWh in summer.

2. E-1 rates are standard "flat" rates and E-7 rates are "time-of-use" rates. Costs were calculated by multiplying the lower tier usage by the lower tier rate, then adding the product of the incremental difference between higher and lower tier rates and the incremental kWh usage in each tier level.

3. Base rates are as follows:

Winter on-peak	\$0.11636
Winter off-peak	\$0.08851
Summer on-peak	\$0.31524
Summer off-peak	\$0.08515

4. The above rates include a \$0.01732 baseline credit, a \$0.01 PUC Energy Surcharge, and the following additional PUC surcharges for usage above baseline:

130-200%:	\$0.05124
200-300%:	\$0.09517
Above 300%:	\$0.11505

5. Rates were effective July 2003.

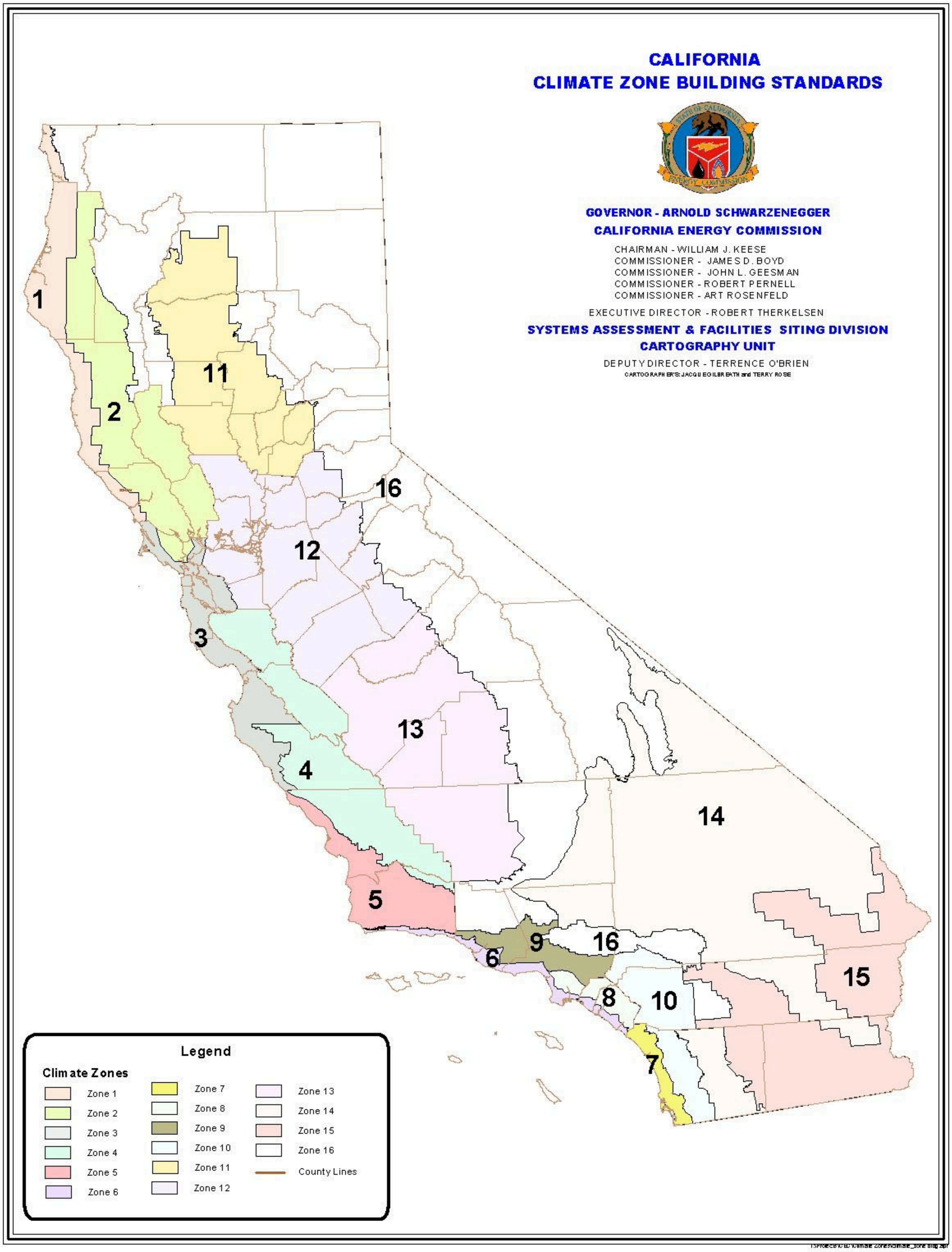
Appendix B: California Climate Zone Descriptions

APPENDIX B
California Climate Zone Descriptions

The table below lists the representative cities that climate zone data are generally based upon. The table also lists winter and summer design temperatures and heating and cooling degree-days for the representative cities. A map of California climate zones is provided on the following page.

Climate Zone	City	Description	Winter Design	Summer Design	Heating Deg. Days	Cooling Deg. Days
1	Arcata (Eureka)	North coastal	35	69	4679	0
2	Santa Rosa	Northern coastal valley	27	96	3065	315
3	Oakland	San Francisco bay area	33	84	2909	128
4	Sunnyvale (San Jose)	Central coastal valley	34	88	2416	444
5	Santa Maria	Central coastal	31	83	3053	84
6	Long Beach	South coastal – Los Angeles	38	90	1606	905
7	San Diego	South coastal – San Diego	42	83	1507	722
8	El Toro (Santa Ana)	Southern coastal valley-south	38	89	1675	972
9	Burbank	Southern coastal valley-north	34	96	1701	1179
10	Riverside	Southern inland valley	32	100	1919	1324
11	Red Bluff	Northern inland valley – hot	29	104	2688	1904
12	Sacramento	Northern inland valley – moderate	31	100	2843	1159
13	Fresno	Central inland valley	28	101	2650	1671
14	China Lake (Barstow)	Southern high desert	22	108	2547	2272
15	El Centro	Southern inland valley	35	111	1216	3794
16	Mt. Shasta (Alturas)	Mountain	-4	96	5890	195

Note: Design temperature and degree-day data are for the city listed in parentheses, and are 0.2% winter and 0.5% summer values. All data are from *Climatic Data for Region X, Arizona, California, Hawaii and Nevada* published by ASHRAE; except cooling degree-day data are from *Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days (California), 1941-1970* published by the National Oceanic and Atmospheric Administration.



CALIFORNIA
CLIMATE ZONE BUILDING STANDARDS
GOVERNOR - ARNOLD SCHWARZENEGGER
CALIFORNIA ENERGY COMMISSION
CHAIRMAN - WILLIAM J. KEESE
COMMISSIONER - JAMES D. BOYD
COMMISSIONER - JOHN L. GEESMAN
COMMISSIONER - ROBERT PERNELL
COMMISSIONER - ART ROSENFELD
EXECUTIVE DIRECTOR - ROBERT THERKELSEN
SYSTEMS ASSESSMENT & FACILITIES SITING DIVISION
CARTOGRAPHY UNIT
DEPUTY DIRECTOR - TERRENCE O'BRIEN
CARTOGRAPHER'S: JACQUE GILBREATH and TERRY ROSE
1
2
3
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10
11
12
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14
15
16
16
Legend
Climate Zones
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12
Zone 13
Zone 14
Zone 15
Zone 16
County Lines

Appendix C: Photos of Demonstration Houses

APPENDIX C
Photos of Demonstration Houses

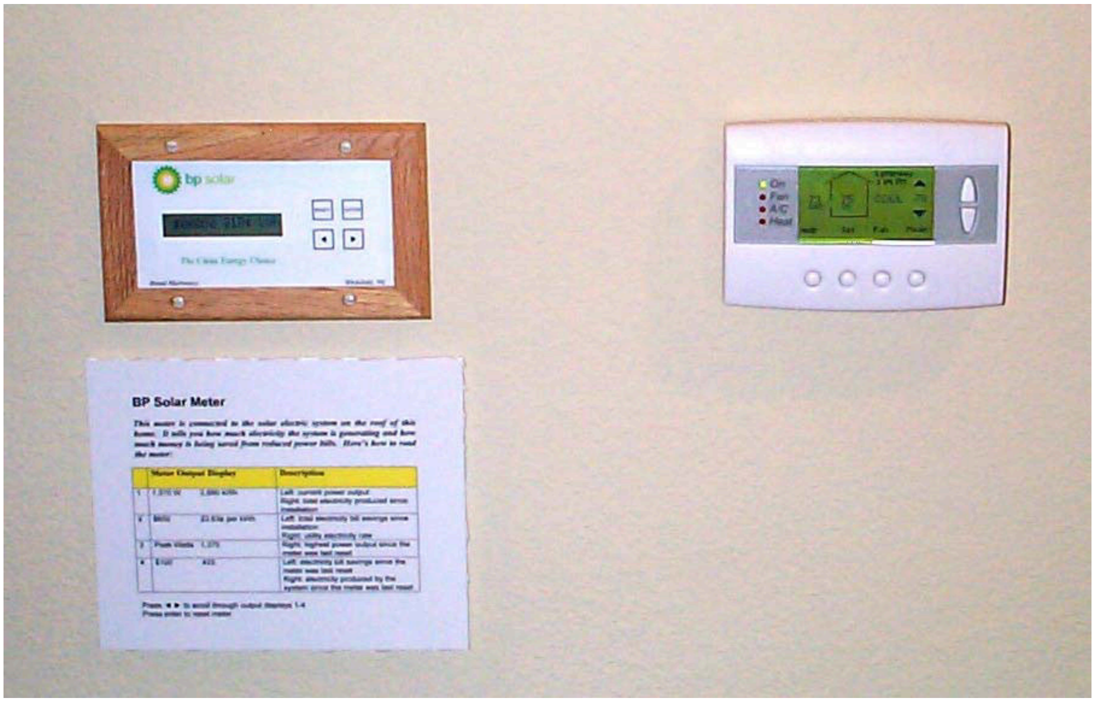
Southwest Elevation, Watsonville House

Southeast Elevation, Watsonville House

NightBreeze Air Handler, Pump, and Data Acquisition System Watsonville House

Outside Air Damper and Air Intake Duct Watsonville House

View of Outside Air Damper/Indoor Air Return from Below Watsonville House

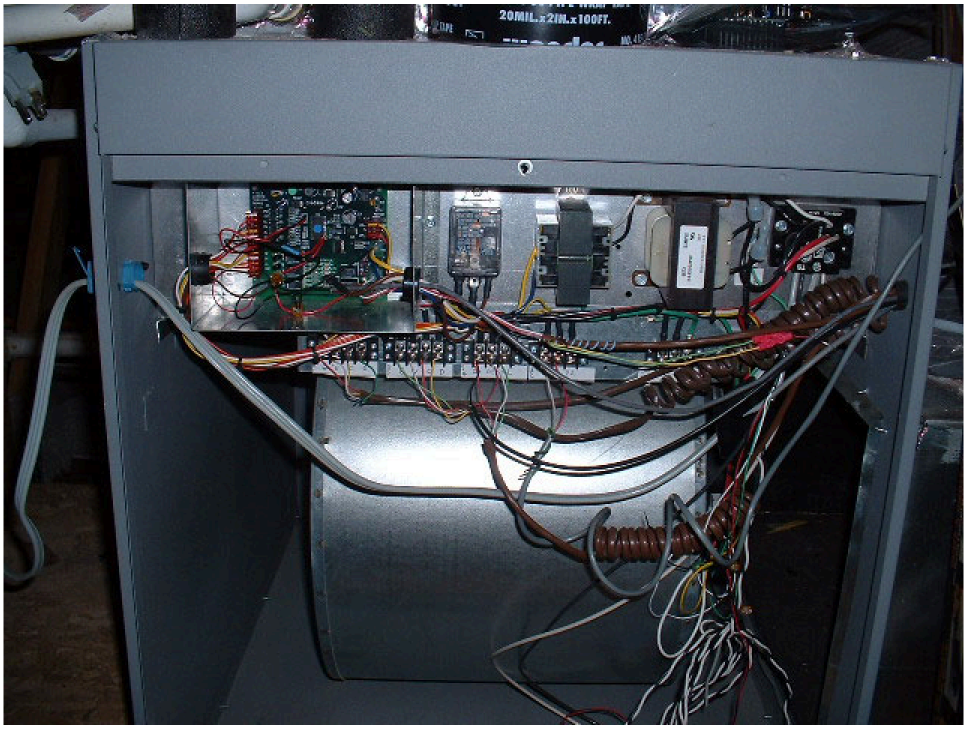


Wall Display Unit (right) and Energy Meter (left)
Watsonville House

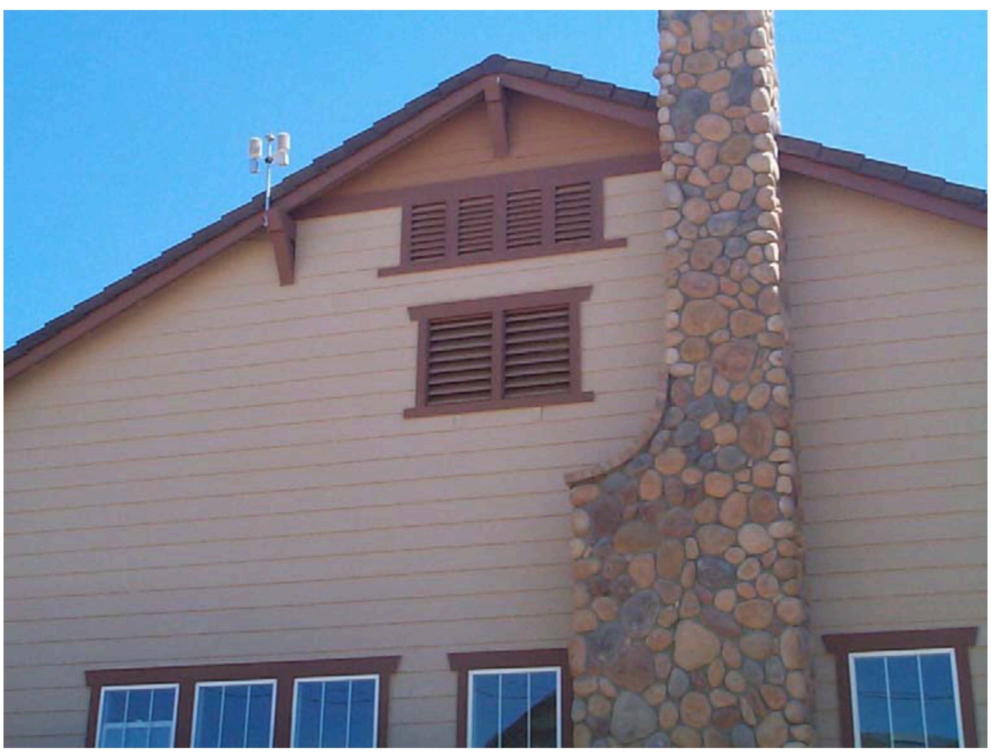
Foundation Prior to Concrete Pour
Livermore House

Detail of Slab Perimeter Insulation & Termite Barrier
Livermore House

Cellulose Wall Insulation
Livermore House



NightBreeze Air Handler with Wiring for Monitoring
Watsonville House

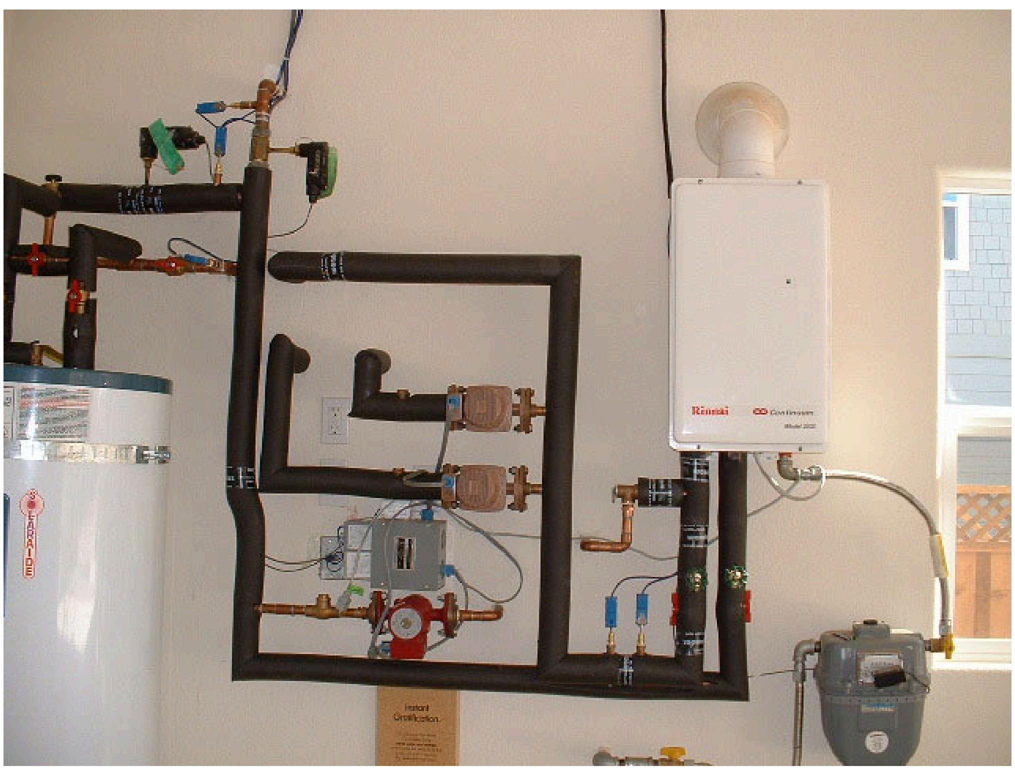


Outside Air Intake Louver (lower) and Weather Station,
Watsonville House

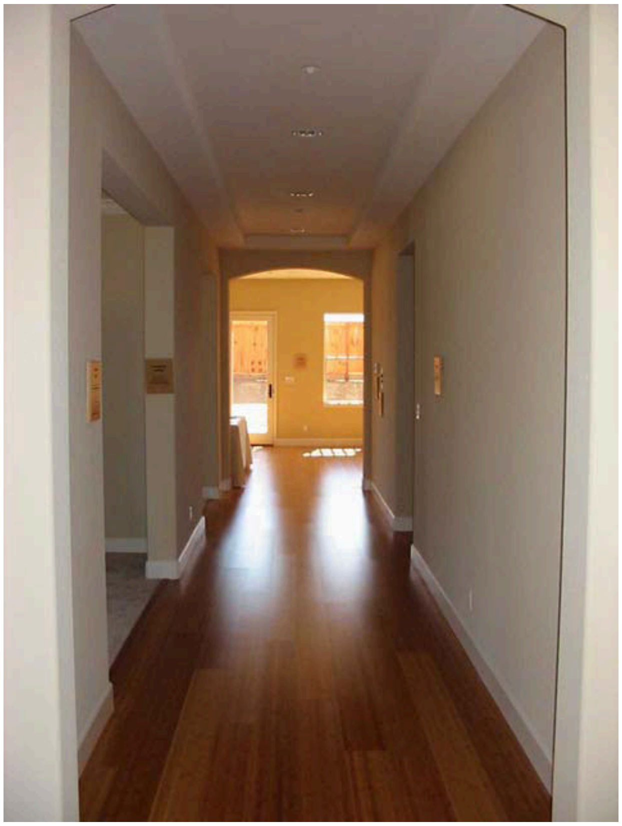
Back (east) Elevation Showing Trellis for Window Shading
Watsonville House

Front (west) Elevation Showing PV Modules
Livermore House

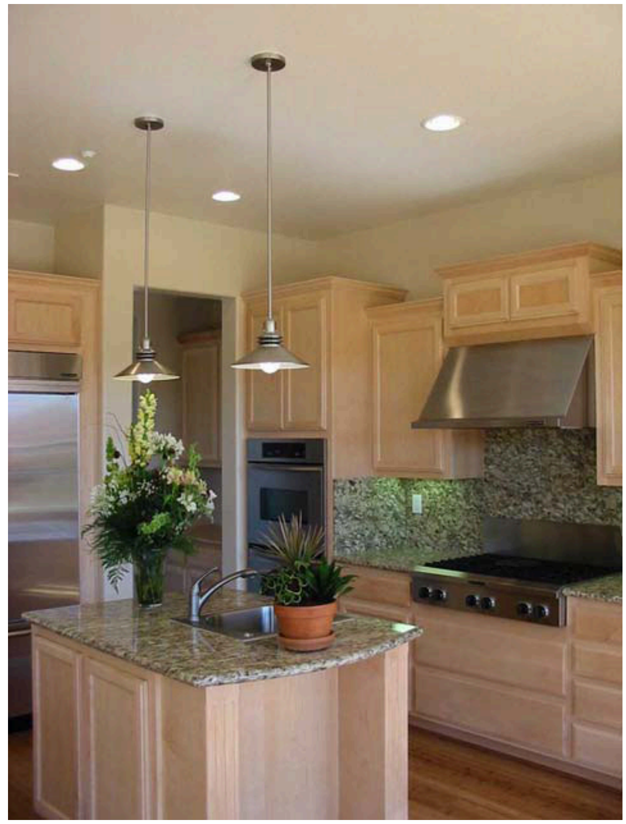
Back Elevation Showing Domestic Hot Water Solar Collectors
Livermore House



View of Garage Interior Wall Showing Tankless Water Heater (right), Solar Storage Tank (left), Air Handler Pumps (upper), & Recirculation Pump (lower)
Livermore House



Hallway Showing Bamboo Flooring Over Slab Livermore House



Kitchen and Fluorescent Lighting Fixtures Livermore House

Appendix D: Detailed Simulation Results

APPENDIX D
Detailed Simulation Results

The values in the tables below were developed from analysis completed using a DOE-2.1E computer simulation that incorporates a special function that emulates the operation of the NightBreeze control. Costs were calculated using the rates listed in Appendix A.

Electrical Energy Usage & Cost, Base Case Model Designed to Comply with Title 24

Climate Zone	Comp kWh	HeatFan kWh	CoolFan kWh	HVAC kWh	Total kWh	Demand kW	Energy Cost (E-1)
CZ 01	0	79	0	79	5354	0.7	$680
CZ 02	1158	109	79	1347	6622	6.2	$871
CZ 03	33	70	4	107	5382	2.8	$684
CZ 04	933	75	68	1076	6351	4.2	$829
CZ 05	33	55	6	94	5369	2.0	$682
CZ 06	522	20	44	586	5861	3.5	$750
CZ 07	854	14	51	919	6194	5.0	$806
CZ 08	1647	24	116	1787	7062	6.4	$948
CZ 09	2161	26	138	2325	7600	7.7	$1,046
CZ 10	2938	39	182	3160	8435	8.1	$1,221
CZ 11	3326	166	215	3707	8982	8.7	$1,333
CZ 12	2262	147	177	2586	7861	7.1	$1,097
CZ 13	4903	119	363	5385	10660	9.0	$1,695
CZ 14	4110	142	292	4544	9819	8.8	$1,520
CZ 15	9249	32	645	9926	15201	13.0	$2,724
CZ 16	911	242	67	1220	6495	4.7	$855

Electrical Energy Usage & Cost, Base Case Model with ACC Improvements

Climate Zone	Comp kWh	HeatFan kWh	CoolFan kWh	HVAC kWh	Total kWh	Demand kW	Energy Cost (E-1)
CZ 01	0	72	0	72	5347	0.7	$679
CZ 02	674	131	127	932	6207	4.2	$802
CZ 03	13	88	2	104	5379	2.6	$684
CZ 04	457	83	110	650	5925	2.9	$760
CZ 05	3	34	0	37	5312	1.0	$674
CZ 06	255	31	60	345	5620	2.7	$716
CZ 07	491	22	119	632	5907	2.9	$759
CZ 08	982	41	259	1282	6557	4.8	$862
CZ 09	1305	32	327	1664	6939	3.9	$926
CZ 10	2126	74	413	2613	7888	6.5	$1,111
CZ 11	2550	265	449	3264	8539	6.6	$1,235
CZ 12	1575	235	302	2112	7387	6.3	$1,003
CZ 13	3745	173	707	4624	9899	6.4	$1,524
CZ 14	3347	226	558	4131	9406	6.5	$1,426
CZ 15	7310	41	1271	8622	13897	7.0	$2,419
CZ 16	606	520	105	1232	6507	4.5	$853

Electrical Energy Usage& Cost, ACC Improved Model with Ventilation Cooling

Climate Zone	Comp kWh	Pump kWh	HeatFan kWh	CoolFan kWh	VentFan kWh	HVAC kWh	Total kWh	Demand kW	E-1 Energy Cost	E-7 Energy Cost
CZ 01	0	108	174	0	195	477	5752	0.9	$735	$611
CZ 02	30	80	102	3	318	532	5807	2.1	$742	$614
CZ 03	0	66	108	0	180	354	5629	0.9	$719	$597
CZ 04	0	62	90	0	272	424	5699	0.9	$728	$600
CZ 05	0	51	87	0	235	373	5648	0.9	$722	$600
CZ 06	0	23	51	0	277	351	5626	0.9	$718	$597
CZ 07	4	17	41	1	307	368	5643	1.4	$720	$598
CZ 08	99	21	34	14	451	619	5894	2.0	$755	$636
CZ 09	153	20	38	21	618	850	6125	2.7	$788	$657
CZ 10	495	28	40	48	753	1363	6638	3.8	$876	$770
CZ 11	899	99	95	70	669	1832	7107	5.1	$955	$853
CZ 12	255	89	97	23	515	978	6253	3.9	$809	$689
CZ 13	1972	65	79	165	966	3247	8522	5.4	$1,240	$1,173
CZ 14	1820	85	79	134	830	2949	8224	5.2	$1,185	$1,120
CZ 15	6474	16	24	491	919	7924	13199	6.3	$2,273	$2,321
CZ 16	11	197	139	6	229	582	5857	1.5	$750	$618

Electrical Energy Savings – ACC-Improved Design vs. Baseline House

Climate Zone	Cooling kWh	Heating kWh	HVAC kWh	% kWh Savings	Demand kW	Energy Cost*
CZ 01	0	7	7	9%	0.0	$1
CZ 02	437	-22	415	31%	2.0	$69
CZ 03	21	-19	2	2%	0.2	$0
CZ 04	434	-8	426	40%	1.3	$69
CZ 05	36	22	58	61%	1.0	$8
CZ 06	251	-10	241	41%	0.8	$35
CZ 07	295	-8	286	31%	2.1	$47
CZ 08	522	-17	505	28%	1.6	$86
CZ 09	667	-6	661	28%	3.8	$120
CZ 10	582	-35	547	17%	1.6	$110
CZ 11	541	-98	443	12%	2.1	$98
CZ 12	562	-88	474	18%	0.8	$94
CZ 13	815	-54	761	14%	2.6	$171
CZ 14	497	-83	413	9%	2.3	$94
CZ 15	1313	-9	1303	13%	6.0	$305
CZ 16	266	-279	0	0%	0.2	$2

*Savings calculated using E-1 rates for Base house and ACC house

Electrical Energy Savings – ACC Improved Design with Ventilation Cooling vs. ACC Improved Design Without Ventilation Cooling

Climate Zone	Cooling kWh	Heating kWh	HVAC kWh	% kWh Savings	Demand kW	Energy Cost*
CZ 01	-195	-210	-405	n/a	-0.2	$68
CZ 02	450	-50	400	43%	2.1	$187
CZ 03	-165	-86	-250	n/a	1.7	$87
CZ 04	295	-70	226	35%	2	$160
CZ 05	-232	-104	-337	n/a	0.1	$74
CZ 06	37	-43	-6	n/a	1.8	$119
CZ 07	299	-35	264	42%	1.5	$161
CZ 08	677	-14	663	52%	2.8	$226
CZ 09	840	-25	814	49%	1.2	$269
CZ 10	1244	6	1250	48%	2.7	$341
CZ 11	1363	70	1432	44%	1.5	$382
CZ 12	1085	49	1134	54%	2.4	$315
CZ 13	1349	29	1377	30%	1	$351
CZ 14	1120	62	1182	29%	1.3	$306
CZ 15	697	2	699	8%	0.7	$98
CZ 16	465	185	650	53%	3	$235

*Savings calculated using E-1 rate for ACC house and E-7 rate for ACC house with vent cooling

Electrical Energy Savings – ACC Improved Design with Ventilation Cooling vs. Base Title 24House

Climate Zone	Cooling kWh	Heating kWh	HVAC kWh	% kWh Savings	Demand kW	Energy Cost*
CZ 01	-195	-202	-398	n/a	-0.2	$69
CZ 02	887	-72	815	60%	4.1	$256
CZ 03	-143	-105	-248	n/a	1.9	$87
CZ 04	729	-77	652	61%	3.3	$229
CZ 05	-196	-83	-279	n/a	1.1	$82
CZ 06	288	-54	235	40%	2.6	$153
CZ 07	594	-43	550	60%	3.6	$208
CZ 08	1199	-31	1168	65%	4.4	$312
CZ 09	1507	-32	1475	63%	5.0	$389
CZ 10	1826	-29	1797	57%	4.3	$452
CZ 11	1904	-29	1875	51%	3.6	$480
CZ 12	1647	-38	1608	62%	3.2	$409
CZ 13	2164	-25	2138	40%	3.6	$522
CZ 14	1617	-22	1595	35%	3.6	$400
CZ 15	2010	-8	2002	20%	6.7	$403
CZ 16	732	-94	638	52%	3.2	$237

*Savings calculated using E-1 rate for Basecase house and E-7 rate for ACC house with vent cooling

Appendix E: Non-compressor Cooling Applications in California

APPENDIX E
Non-Compressor Cooling Applications in California

This map was developed using methods described by Huang (1999). The blue areas denote locations where 1500 CFM of ventilation cooling used with a house designed to ACC standards will maintain indoor temperatures at or below 78°F through five-day "heat waves" using ventilation cooling alone. In the green areas, a 1½ ton air conditioner is needed to supplement ventilation cooling to limit indoor temperatures to 78°F or below. In the brown areas, an air conditioner larger than 1½ tons is required.